VOL. 1 No. 10 OCTOBER 1936

Philips Technical Review

DEALING WITH TECHNICAL PROBLEMS
RELATING TO THE PRODUCTS, PROCESSES AND INVESTIGATIONS OF
N.V. PHILIPS' GLOEILAMPENFABRIEKEN

EDITED BY THE RESEARCH LABORATORY OF N.V. PHILIPS' GLOEILAMPENFABRIEKEN, EINDHOVEN, HOLLAND

THE "PHOTOFLUX"

A LIGHT-SOURCE FOR FLASHLIGHT PHOTOGRAPHY

by J. A. M. VAN LIEMPT and J. A. DE VRIEND.

Summary. The "Photoflux" is a light-source suitable for flashlight photography. It consists of a bulb containing oxygen in which a long wire of a combustible alloy is ignited electrically. This article deals with the method employed for measuring the quantity of light emitted and the luminous intensity as a function of the time.

Introduction

The art of photography is now one hundred years old and is almost as old as are attempts to devise means of artificial illumination enabling photographs to be taken when natural sunlight is either lacking or too weak. At the present time two types of artificial light sources are employed in photography:

1) Light-sources for studio lighting by means of which a large number of photographs can be taken in rapid succession.
2) Light-sources which can be used once only and which furnish a very powerful light for a brief period of time, this characteristic being implied in their ordinary name of "flashlights".

A light-source of the latter type is exceptionally suitable for taking snapshots and must satisfy, *inter alia*, the following requirements:

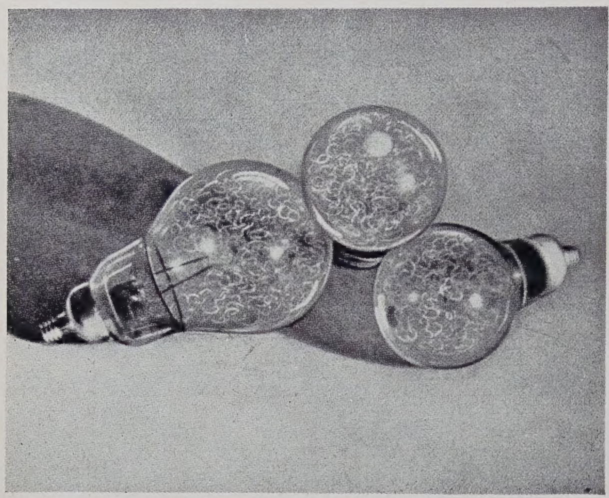
a) It must generate an intense light which must however not be embarrassing to the subject being photographed.
b) It must operate without even the least complex or heavy current source.
c) It must not introduce any fire hazard or other undesirable condition, such as smoke or odour.
d) It must always be ready for use, also during rainy and stormy weather.
e) It must be compact in design and light in weight.

It is comprehensible therefore why flashlight powder, which only satisfies requirements b) and e) and not by any means requirements c) and d), has been rapidly replaced during recent years by flash bulbs in which the whole process of the rapid light-generation by combustion takes place in a totally-enclosed glass bulb. This class of light generator includes the "Photoflux" in which the duration of the flashlight is only about 1/40 of a second, thus being considerably below the reflex time of the eye of approx. 1/10 sec. The use of this source thus eliminates that screwing-up of the eyes in flashlight photographs, which has been a common fault of these photographs in the past.

Description

The "Photoflux" (*fig. 1*) consists of a glass bulb 55 or 70 mm in diameter filled with oxygen and enclosing a wire of an aluminium alloy containing approx. 8 per cent magnesium. This wire is only 0.035 mm thick and is in the form of a crumpled mass, so that it is distributed as uniformily as possible over the whole interior of the bulb. The volume occupied by the whole wire is not greater than that of a hailstone. After careful evacuation the bulb is filled with pure dry oxygen at a low pressure. In the middle of the bulb and thus completely surrounded by the crumpled wire is a small incandescent filament carrying a weak charge of priming paste. If the filament is brought to incan-

descence, e.g. by connecting the lamp to a flashlamp battery, the priming is ignited. Ignition is transmitted to the wire which burns very rapidly



17344

Fig. 1. The "Photoflux" flashbulb.

in the oxygen atmosphere. Since the length and thickness of the wire are the same in all lamps and the quantity of light evolved is proportional to the weight of the wire, there is every guarantee that all lamps of the same type will give the same intensity of light.

Should inleakage develop in the lamp after leaving the works, for instance through a crack in the bulb, the latter will fill with air through the crack owing to the low pressure of the contained oxygen. A lamp of this type with a thin-walled bulb and a much higher gas pressure than the initial oxygen filling would prove dangerous on ignition, since the bulb cannot withstand the sudden increase in pressure generated on combustion. To avoid this hazard a deep-blue spot of a cobalt salt is provided in the bulb which turns a light rose colour by absorption of moisture when air leaks into the lamp. The salt used is so sensitive that the humidity of the air even on the driest and coldest days is sufficient to produce a change in colour. Lamps with a bright rose instead of a blue indicator spot are therefore defective and must not be used owing to the liability of shattering the bulb.

Since the combustion responsible for the generation of light takes place in a sealed bulb, the "Photoflux" operates with complete reliability in all weathers. The fire hazard has been completely eliminated and the combustion-products formed remain in the bulb.

The "Photoflux" is preferably used with a reflector so that the greater part of the spherically-radiated light is utilised to good purpose and the light is intensified four to five times in the required direction. The simple Photoflux millboard reflector makes a very good reflector, where a more efficient and hence more expensive unit is not essential. The "Photoflux" is fitted with either a miniature cap, similar to that on flashlamp bulbs, or with standard screw and bayonet caps as on ordinary incandescent lamps. The „Photoflux" with incandescent lamp cap can be used with either a 4-volt battery or a lighting mains supply. For the latter case a rapid-acting fusible element is incorporated in the lamp to protect the house fuses. The actinic energy of the light from the „Photoflux" is given in the following table, which applies to the smallest Type I now on sale.

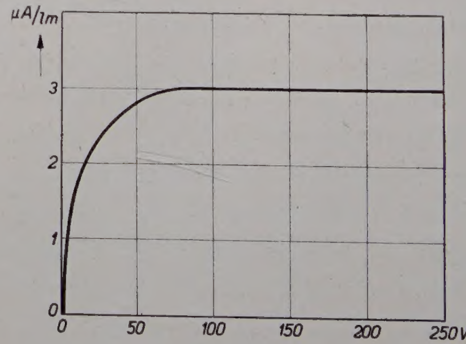
Illumination Table for „Photoflux" Type I when using a lamp with reflector

Distance (in metres) from the light source to the object being photographed for different apertures.

Negative Material	Aperture							
	3.5	4.5	6.3	11	12.5	18	21	32
Normal orthochromatic	8	6.5	4.5	2.6	2.3	1.6	—	—
Rapid orthochromatic	12	9	7	3.7	3.2	2.2	1.9	—
Normal panchromatic	14	11	8	4.5	4	2.8	2.4	1.6
Rapid panchromatic	20	16	11	6.5	6	4	3.4	2.2

Quantity of Light and Light Yield

The photographic value of a flashlight is expressed essentially by the quantity of light (luminous flux multiplied by the time). It may be measured with a photo-electric cell in conjunction with a spherical integrating photometer and an electrostatic voltmeter. In our measurements we used a type 3510 photo-electric cell (a vacuum cell with potassium cathode) whose characteristic is given in *fig. 2*. This figure shows that the photo-



17413

Fig. 2. Characteristic of the Philips type 3510 photo-electric cell.

electric current in the cell is practically independent of the anode voltage as long as the latter does not drop below 50 volts, a feature which is very convenient for the present measurements. The colour sensitivity of the cell is roughly the same as that of an orthochromatic plate, the red limit being approximately at 7500 Å.

To measure the light output the following arrangement was used (*fig. 3*). The "Photoflux" *2* was suspended in an Ulbricht sphere, and the photoelectric cell *6* connected to the electrostatic voltmeter *7*. The condenser which is incorporated in the design of this voltmeter is initially charged to 300 volts by a Wimshurst machine. As soon as light falls on the cell, the condenser is discharged by the photo-electric current and since the current is independent of the anode voltage (above 50 volts), the quantity of light generated is proportional to the voltage difference measured on the electrostatic voltmeter before and after discharge, provided the lowest voltage is not under 50 volts. The capacity of the condenser referred to is matched to the quantity of light expected by connecting one or more other condensers in parallel.

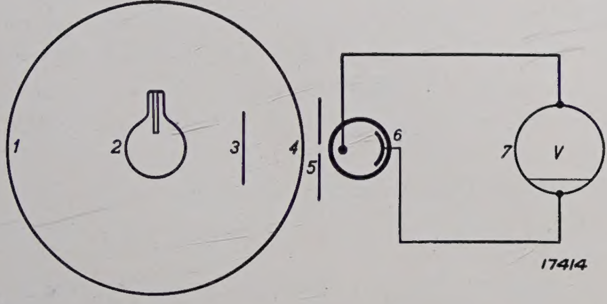


Fig. 3. Arrangement for photometric examination of the flashbulbs. *1* Ulbricht sphere; *2* "Photoflux"; *3* screen; *4* opal glass plate protected by the screen 3 against direct radiation from the "Photoflux"; *5* diaphragm; *6* photo-electric cell; *7* electrostatic voltmeter.

After the photometer has been calibrated with an incandescent lamp whose luminous flux has itself been calibrated and which is switched on for a definite period, the light output of the flash-bulb can be calculated in lumens per sec. Thus for the "Photoflux type" I a value of 25 000 lumen secs was obtained and for type II 50 000 lumen secs. Since the duration of the flash is about 1/40 of a second, the light output of 25 000 lumen secs or 1 000 000 lumens in 1/40 of a sec corresponds to the light emitted in the same time by 1000 lamps of 100 Dekalumen.

The heat of combustion of the alloy wire was measured in a calorimetric bomb and was found to be 28.9 watts-secs per mg. Since the "Photoflux" type I contains 27 mg of alloy wire, the light output is:

$$\frac{25000}{27 \cdot 28.9} = 32 \text{ lumens per watt}$$

This corresponds to the light output of a black body at a temperature of 3100 °K.

Luminous Intensity as a Function of the Time

In addition to the total light-output of the flashbulb the variation of the light output as a function of the time is also of interest. The measuring apparatus used consists essentially of a photoelectric cell and a cathode ray tube. The photoelectric current generated by the light from the "Photoflux" produces a voltage drop at a non-inductive resistance of 50 000 ohms. The terminals of this resistance are connected to the deflecting plates which deflect the cathode ray perpendicularly to its direction; the second pair of deflecting plates is not employed and is earthed.

In *fig. 4* the arrangement of the apparatus used is shown diagrammatically. At the top is the high-vacuum cathode ray tube (*1*), and on the right the

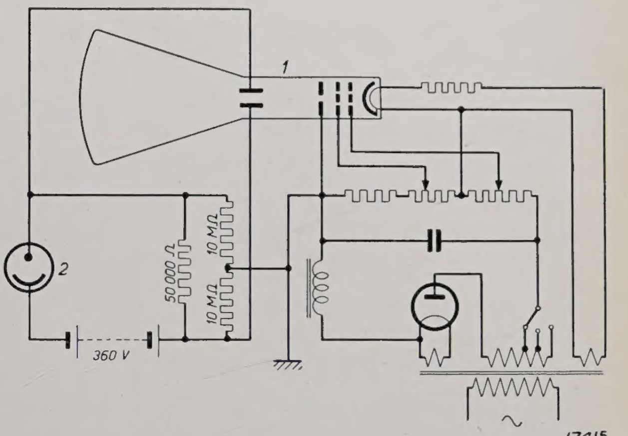


Fig. 4. Apparatus for measuring the light intensity as a function of the time. *1* cathode ray tube; *2* Type 3512 photo-electric cell.

mains connection for furnishing the heating current for indirectly heating the cathode and, through a series of potentiometer tappings, the D.C. voltages for the grid and the two anodes. At the bottom left is the photo-electric cell (*2*) whose anode voltage is furnished by a 360-volt battery. The cell with battery is bridged by a 50 000-ohm resistance and connected in parallel with two series-connected resistance leaks of 10 megohms, whose junction is connected to the deflection plates and the earthed anode of the cathode ray tube. In the arrangement shown a vacuum cell with caesium cathode, type 3512, was used, since no amplifier

is employed here and a high sensitivity is therefore essential. The photo-electric cell is enclosed in a metal housing mounted on the Ulbricht sphere. Between the sphere and cell an adjustable diaphragm is fixed. When the flashlight is burnt in the spherical photometer, a beam of light falls on the photo-electric cell which is reduced to a suitable intensity by the diaphragm. The voltage drop at the 50 000-ohm coupling resistance is then used to control the cathode ray.

The vertical deflection of the cathode ray produced in this way is registered by means of an oscillograph camera with extra high-power optical system. The photographic plate is displaced horizontally in the camera by means of a released spring. On unlatching the locking pawl, which releases the stretched spring in the camera, a switch is released at the same time which switches on the "Photoflux", so that the cathode ray is deflected the moment the camera plate starts moving. A small neon lamp fed from a 50-cycle A.C. mains supply is also photographed to provide a time base, a black mark being produced on the plate at intervals of 0.01 sec. The oscillogram

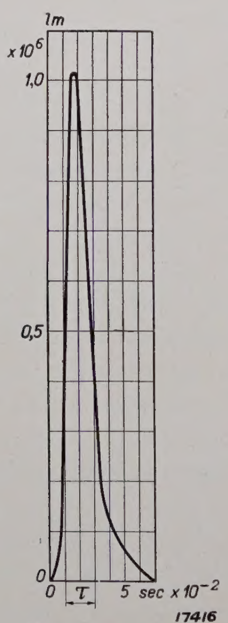


Fig. 5. Light-intensity-time curve of the "Photoflux". τ is the speed of the flash.

obtained can, if necessary, be enlarged four to five times with an enlarger and can be converted to absolute units since the total quantity of light in lumens per second is known. The variation in light intensity of the type I bulb as a function of time is shown in *fig. 5*.

Lag on Ignition

In addition to the light intensity-time curve the socalled lag on ignition is also an important characteristic, i.e. the time elapsing between the moment the lamp is switched on and the instant the "Photoflux" commences to radiate light. To measure this lag the arrangement just described has been slightly amplified. A Philips E 499 radio

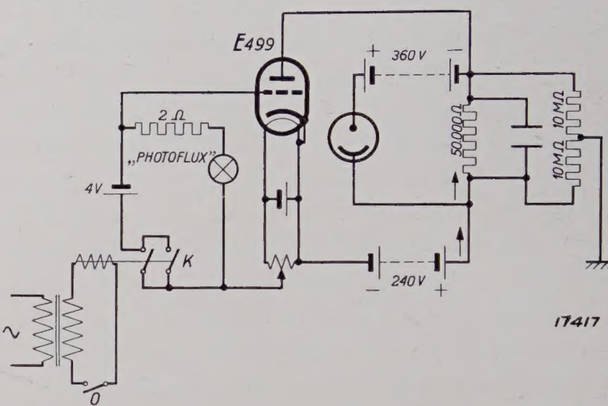


Fig. 6. Diagram of arrangement for measuring the lag in ignition of the "Photoflux".

valve is connected in parallel with the photo-electric cell (*fig. 6*), the valve being fed from e.g. a 240-volt battery. On operating the camera switch *O* a relay *K* is energised which connects the "Photoflux" to a 4-volt accumulator through two contacts (which are here connected in parallel in order to ensure good circuit-closing contact). A 2-ohm resistance is connected in series with the accumulator to adapt the arrangement to the working conditions obtaining when using a pocket-lamp battery.

On switching on the "Photoflux" the accumulator is inserted, at the same time and through the same contact, between the cathode and the grid of the E 499 valve, so that the grid bias of the valve is increased by 4 volts as compared with that previously adjusted at the potentiometer through the filament voltage of the E 499 valve, whereby the anode current of the valve is suppressed. This anode current previously flowed through the 50 000-ohm coupling resistance and caused a deflection in the cathode ray tube which disappeared on switching on the "Photoflux". When light commences to be radiated from the "Photoflux" the cathode ray is again deflected. The time elapsing between these two deflections is the required lag on ignition. In addition to the lag the oscillogram also includes the whole of the light intensity-time curve.

An oscillogram of this type is reproduced in *fig. 7*, which includes not only the light-time diagram, as shown in fig. 5, but also the actual lag on ignition. The lag in the "Photoflux" is about 0.035 sec;

it varies very little from bulb to bulb and is also not appreciably affected by the resistance in the circuit, i.e. ignition is obtained just as rapidly

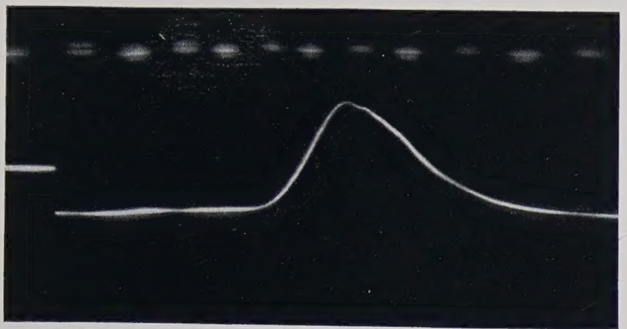


Fig. 7. Oscillogram of the lag in ignition of the "Photoflux" and the variation of light intensity with time.

with a new as with a partially-exhausted pocket-lamp battery.

The absolute value of the lag is of less moment than the fact that it is practically constant, an important characteristic when using the "Photoflux" in conjunction with synchronised shutter releases. The latter are small units mounted on the camera for synchronising the shutter with the flash-bulb. The simplest arrangement of this type consists of an electric switch which is operated at the same time as the shutter cable release. With a single manual operation the shutter is first opened and a very short time later the flash-bulb is switched on (for the sake of convenience the bulb is mounted in a holder on the camera), 0.035 sec later light is emitted and lasts for only about 0.05 sec, when the shutter is automatically reclosed. To ensure satisfactory exposure the shutter in this arrangement must remain open for about 1/10 of a second.

In a more refined arrangement the flash-bulb can, for instance, be switched on first and immediately after the shutter released, so that its opening coincides with the emission of light. To obtain well-defined exposures and to avoid any interference from artificial light sources and windows in the field of view, the shutter speed can be reduced to 1/100 to 1/500 of a second without disadvantage. The only precaution necessary here is that the shutter is open during the short time the maximum quantity of light is emitted from the flash-bulb. It is evident that in both cases, and particularly in the latter, the lag on ignition of the flash-bulb must be very constant if light emission is to be obtained exactly at the moment required.

Practical Speed of the Flash

It will be apparent that the time during which the light is strong enough to act on the photographic plate is smaller than the base of the light-time curve diagrams in figs. 5 and 7. The spurs at the two ends of the light-time curve are of negligible importance since the sensitivity of the plate drops considerably below a certain intensity threshold.

To determine the actual speed of the flash we can compare exposures of a moving object obtained with the flash-bulb with similar exposures made with a uniform illumination and using an ideal, previously calibrated, instantaneous shutter, and estimating at which exposure time photographs of equal definition are obtained.

This has been done by photographing with the "Photoflux" a rotating black disc on which several hexagonal white and grey stars with black letters are arranged at different distances from the centre. The requisite distance of the "Photoflux" from the disk was determined from an illumination formula [1]), so that the correct blackening of the negative was realised. The exposures obtained were compared with those of the disk rotating at the same velocity when illuminated by a light-source giving a uniform luminous flux and with previously calibrated shutter speeds of 1/10, 1/25, 1/35, 1/50 and 1/100 of a second [2]). In this way the practical speed of the flash was found to be 1/35 to 1/50 of a sec, which is in agreement with fig. 5, if it is assumed that the spurs on both sides of the light-time curve produce no latent blackening of the plate up to light intensities of 20 to 30 per cent of the maximum value. For these comparative exposures a shutter should be used in which the inertia of the blades is very small. With shorter exposure times (below 1/25 sec) a diaphragm can be used with advantage, in order that the illuminated diagram of the shutter is a rectangle.

Colour of the Light

The spectrum of the light emitted by the "Photoflux" was recorded with a Hilger spectrograph Type E 3 with quartz prism on Ilford Special Rapid panchromatic plates. The negative was printed through a grey wedge using the method of Visser [3]) so that the length of the spectral lines

---

[1]) J. A. M. van Liempt, Rec. Trav. chim. Pays-Bas, **53**, 471, 1934.

[2]) For information on the calibration of instaneous shutters using the cathode ray tube see: J. A. M. van Liempt and J. A. de Vriend, Z. Phys., **95**, 198, 1935.

[3]) S. H. R. Visser, Physica, **1**, 497, 1934.

on the print increases with their intensity. The result obtained is indicated in *fig. 8*. The spectrum is seen to be continuous and reaches from about 3500 Å into the infra-red. A more intense band and a stronger line occur at 5200 Å (Mg) and 5900 Å (Na).

Furthermore, the chromatic reproduction on different plates was measured with the Agfa graded colour table [4]). We found the following values:

Plate [5])	Red	Yellow	Green	Blue
Blue-sensitive plate	30	15	30	160
Isochromatic plate	30	30	30	160
Orthochromatic plate	30	20	30	180
Panchromatic plate I	180	80	30	100
Panchromatic plate II	70	60	50	120
Panchromatic plate III	90	50	40	120

For comparison, the results are given below of measurements on the same plates using daylight with a clear sky and facing the north. As may be seen the reproduction of colours with "Photoflux" illumination is better than with daylight.

The colour-scale temperature of the light from the "Photoflux" was determined by comparing

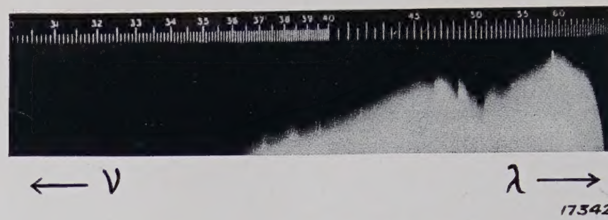


Fig. 8. Spectrum of the "Photoflux".

the photographic reproduction of colour with other light sources of known colour-scale temperature. The colour diagram of von Lagorio [6])

Plate [5])	Red	Yellow	Green	Blue
Blue-sensitive plate	30	10	25	180
Isochromatic plate	30	20	30	180
Orthochromatic plate	30	15	30	180
Panchromatic plate I	90	40	30	180
Panchromatic plate II	60	40	40	140
Panchromatic plate III	60	30	30	160

was obtained for these light sources and for the "Photoflux" on different panchromatic plates. It was found that the colour-scale temperature of the "Photoflux" is slightly higher than that of the carbon filament lamp, viz., about 4000 deg. abs. [7]).

4) H. Arens and J. Eggert, Z. wiss. Phot., **29**, 239, 1930.
5) The panchromatic plates I, II and III were obtained from three of the principal makers.
6) A. von Lagorio, Phot. Ind., **23**, 629, 1930.
7) J. A. M. van Liempt and J. A. de Vriend, Z. wiss. Phot., **34**, 237, 1935.

RECTIFIERS FOR TELEPHONE EXCHANGES

Summary. For telephone installations a D.C. supply is required with very constant voltage and low internal resistance. A rectifier is described which satisfactorily meets these requirements, being designed for feeding small telephone installations without the aid of a battery.

Charging of Telephone Batteries

Batteries are employed in telephone exchanges all over the world for furnishing the current requirements of microphones and relays. Initially it was usual to equip these exchanges with a double set of batteries, each set being employed alternately so that the idle batteries could be recharged while the other set was in service. During recent years charging arrangements have been constructed by means of which the batteries can be charged during service, thus making spare battery sets superfluous. For this socalled "buffer operation" in telephone exchanges the rectifier is a very suitable supply unit since it has no moving parts, requires no attendance, operates quite noiselessly and also has a satisfactory efficiency. Moreover, the rectifier can be set up close to the battery, thus considerably shortening the connecting cables.

The batteries can be charged by either of two methods:

a) By means of a rectifier which is set in operation automatically as soon as the charge has dropped below a specific minimum, and which again disconnects itself when the battery has been fully charged;

b) By means of a socalled "buffer rectifier" which is in continuous operation.

With the buffer rectifier the charging current is so adjusted that the rectifier just makes up the average discharge current. The battery can then be made much cheaper as its capacity has to be merely sufficient to maintain the service on a temporary failure of the mains supply or when during peak traffic periods a greater amount of current is consumed than can be supplied from the rectifier.

A Rectifier as a Battery Substitute

By using the buffer rectifier, the battery can in fact be dispensed with altogether and the rectified alternating current smoothed by a filter. The problem whether this method offers advantages in certain cases has long been the subject of investigation.

A feature in favour of batteries is that a disturbance in the mains supply does not interfere with the telephone service itself. But a battery is not always necessary. In most private telephone installations a breakdown in the supply is not to be anticipated, since a failure in the power supply occurs only rarely and is then only of short duration. Moreover, a large telephone installation, such as is commonly used in large buildings and warehouses, can be connected to two different sections of the mains supply where a failure cannot take place in both together.

When using a rectifier for a direct supply of a telephone network the direct voltage must as far as possible be independent of the load; a filter must also be provided as otherwise the ripple of the current furnished by the rectifier will produce an audible hum in the telephone circuits.

A valve rectifier is described below which operates without a battery and which is suitable for feeding small telephone exchanges, e.g. house telephone installations in warehouses and factories.

Fig. 1 gives the general circuit diagram. The principal components of the rectifier are the rectifying valves B_1, B_2 and the filter which is made up of the choke coils L_1, L_2 and the condensers C_1, C_2. Of the various types of rectifying valve available the gasfilled valve offers the advantage of having a voltage loss independent of the load, so that a compensating arrangement can be dispensed with. Gasfilled rectifying valves with oxide cathodes are particularly suitable for the present purpose.

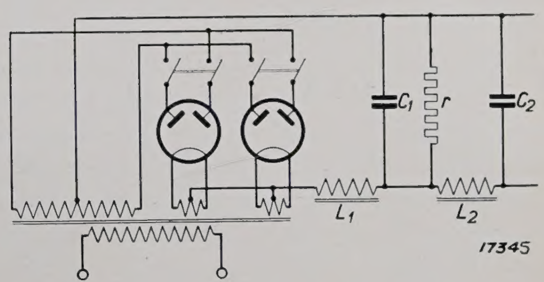


Fig. 1. Diagrammatic circuit of the telephone rectifier. The principal components are the rectifying valves and the filter composed of C_1, C_2, L_1 and L_2. When one valve is running, the other valve cannot start as its starting voltage is higher than the running voltage of the other valve. The idle valve however starts to operate automatically as soon as the other valve ceases to function.

This valve has moreover a very long life. *Fig. 2* shows the efficiency of the two-phase 10-amp rec-

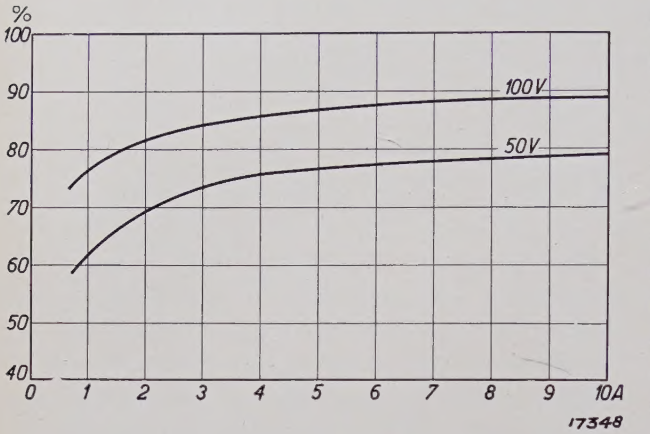


Fig. 2. Efficiency of the gas filled rectifying valves Type 1788 for voltages of 50 and 100 volts plotted as a function of the current intensity.

tifying valve type 1788 plotted as a function of the current for direct voltage outputs of 100 volts (maximum) and 50 volts. At 50 volts the efficiencies at 5 and 10 amps current are 76 and 79 per cent respectively. At 100 volts the efficiencies are 86 and 89 per cent respectively.

The filter

A two-phase rectified alternating voltage of 50 volts, 50 cycles, has *inter alia* an A.C. component of 100 cycles and approx. 25 volts eff., which must be suppressed sufficiently so that no humming is audible in the telephones [1]).

The filter consists in its simplest form of a choke coil through which the charging current passes and a condenser in parallel with the output terminals of the rectifier. As necessary a series of these stages are connected in series (see e.g. fig. 1). The filter circuit employed for a rectifier used for directly feeding a telephone network must have an extremely small D.C. resistance in order to keep the output voltage constant and independent of the load.

The degree of smoothing is determined to a first approximation by the product of self-induction L of the choke coil and the capacity C of the condenser. Within certain limits L can be made small and C very large or vice versa [2]). To avoid cross-talking the A.C. resistance of the source of supply must be low. The self-induction values are therefore made as low as possible and the capacity C_2 very large. Electrolytic condensers are particularly suitable for this purpose as they enable high capacities to be coupled with compact dimensions and with a low weight.

The voltage furnished by the rectifier is practically constant over a wide current range, but increases with a very low load up to the peak value of the rectified alternating voltage, while the normal running voltage E_0 is much smaller. To avoid the voltage fluctuations which may result therefrom a resistance r is connected in parallel with the condenser C_1, this resistance shown in fig. 2 permits a minimum load to be applied. The value of r is so chosen that the voltage of the rectifier on no load has dropped to E_0.

In many telephone installations the feed circuits for the microphones and relays can be kept separate. Since the direct current for the relays does not have to be smoothed to the same degree as the microphone current, while the direct voltage in the microphone circuit need not be kept as rigidly constant as in the relay circuits, the filter at the rectifier can with advantage be split up. *Fig. 3* gives the general circuit details for an arrangement

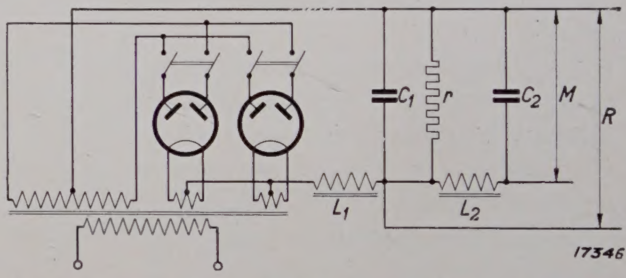


Fig. 3. Circuit diagram of a telephone rectifier with separate terminals for the microphones (M) and the relays (R). The voltage at terminals R is more constant but less well smoothed than that at terminals M.

of this type. The relays are connected to the terminals R and the microphones to the terminals M.

The last portion of the filter composed of L_2 and C_2 here also acts as an interference-suppression filter eliminating the crackling noises emanating from the relays, in addition to smoothing the direct current. In a rectifier designed on the lines of the circuit in fig. 1 these disturbances are suppressed by the condenser C_2 which for this purpose must therefore have a much greater capacity.

Reliability in Operation

As may be seen from the circuits in figs. 1 and 3 two rectifying valves connected in parallel are employed. The starting voltage of gas-filled valves

1) At 100 cycles this limit is located at approx. 0.2 volt. Cf. for further information J. G. W. Mulder and D. M. Duinker, Over het afvlaksysteem bij het laden van telefoonbatterijen gedurende het bedrijf. De Ingenieur **46**, E 27, 1931.

2) Cf. D. M. Duinker, Discussion on "Some considerations in the design of hot cathode mercury-vapour rectifier circuits", J. Inst. el. Eng., **76**, 421, 1935.

differs slightly from valve to valve, but is always greater than the arc voltage so that of two valves in parallel the one with the lower starting voltage will come into operation first and at the same time prevent the starting of the other valve. In this way one valve acts as a reserve and takes over automatically immediately the other valve fails. The temperature of the filament in these valves is only about 950 °C., and is thus so low that vaporisation is of no account so that the spare valve remains in excellent condition. The current consumption of the hot cathode in the 10-amp valve in only 20 watts, so that also in this direction there is no objection against a second filament being continuously in circuit. A double pole anode switch is incorporated in the rectifier for each valve, such that immediately the working valve is switched of the other valve is switched on. In this way it is possible to test each valve without breaking the continuity of supply. A defective valve can be replaced without any interruption in service.

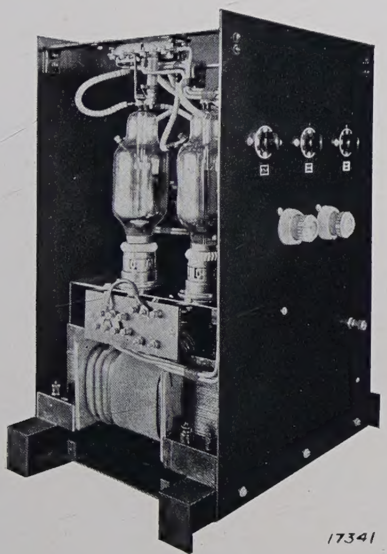


Fig. 4. View of a telephone rectifier for 50 volts and 7 amps D.C. The unit is wired as shown in the diagram in fig. 3. It is suitable for connection to a single-phase A.C. mains supply and can be adjusted for various supply voltages between 190 and 260 volts (50 cycles).

Electrical Construction

The apparatus shown in *fig.* 4 is suitable for connection to a single-phase A.C. mains supply and can be adjusted for various supply voltages. It is constructed for a voltage of 50 volts with a maximum current of 7 amps. The efficiency is shown graphically in *fig.* 5. The voltage ripple occurring at the output terminals is less than 0.1 volt at 100 cycles, and with this rippling no hum is audible.

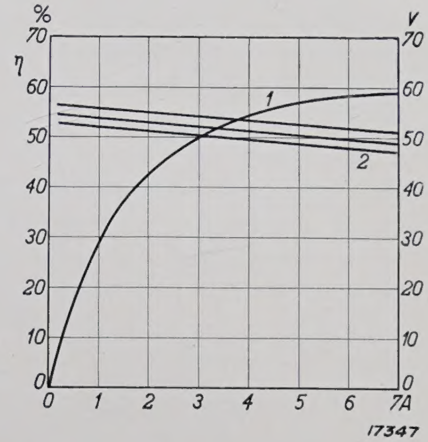


Fig. 5. *1* Efficiency of the rectifier shown in fig. 4, plotted as a function of the current intensity. 2 Direct voltage output plotted as a function of the current intensity. As the current increases up to full load the voltage gradually drops with about 8 per cent. To correct for small voltage fluctuations the transformer primary is provided with three tappings, which correspond to the three curves in the figure.

Rectifiers of this type for furnishing a direct supply to telephone installations and for buffer operation are now supplied for outputs up to several kilowatts.

Compiled by H. J. J. BOUMAN.

ELECTRICAL FILTERS III

Vacation course, held at Delft, April, 1936.

By BALTH. VAN DER POL and TH. J. WEIJERS.

LOW-PASS FILTER SECTIONS.

Summary. In this article the characteristics of non-dissipative low-pass filter sections are analysed by the method described in the previous issue of Philips Technical Review. A short discussion follows of the effect of the losses and the design of compound filters, whose input and output impedances are practically equivalent to pure resistances independent of the frequency. In conclusion a diagrammatic summary is given of the data and formulae for the design of low-pass filter sections. The appendix contains a summary of the formulae which were deduced in the article: Electrical Filters II.

Introduction

The general characteristics of T-sections, Π-sections and half-sections which were deduced in the previous article will now be applied for deriving the simplest forms of low-pass, high-pass and band-pass filter elements and their characteristics. In each case we shall take a simple form of filter element as the fundamental type and from this derive the other type with the aid of m-transformations. We shall see later how from the sections available a compound filter can be built up to satisfy specific requirements.

Low-Pass Filter Sections

The function of a low-pass filter consists in transmitting all frequencies below a certain limiting frequency with the minimum degree of attenuation and to damp all frequencies above ν_1 in a given ratio. We shall in the first instance consider ideal filter sections composed of pure reactances. We shall see later what effect the real resistances of filter elements can exercise.

a) Fundamental Form. As a basic form we shall take the simplest form of low-pass filter section. We shall again denote all magnitudes relating to the fundamental form with an accent. The complete sections Z_1' and Z_2' are made up of a self-inductance L_1' and a capacity C_2' respectively, thus:

$$\left.\begin{aligned} Z_1' &= j\omega L_1' \;; \\ Z_2' &= \frac{1}{j\omega C_2'} \;. \end{aligned}\right\} \quad \ldots\ldots \quad (32)$$

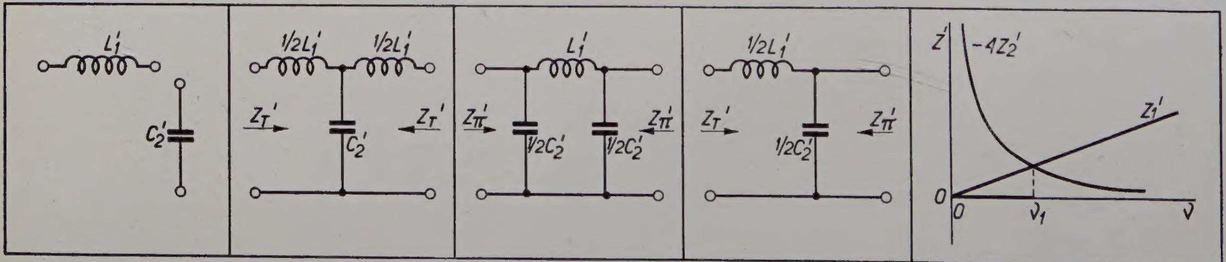
A T-section, a Π-section and a half-section can be formed from these elements in the usual way. As shown in the previous article (p. 274) the transmission bands of these sections coincide and are determined by $-1 < Z_1/4\,Z_2 < 0$; Z_1 and $4\,Z_2$ are in this region of opposite sign, while Z_1 and $-4\,Z_2$ are of the same sign. Moreover $|Z_1| < |4\,Z_2|$. If now in one graph Z_1 and $-4\,Z_2$ are plotted as a function of the frequency, the transmission band is characterised by the fact that Z_1 lies between the abscissa and $-4\,Z_2$. For the filter section considered *fig. 8* represents this diagram of reactances. From this we see that Z_1' lies between the abscissa and $-4\,Z_2'$ for all frequencies between $\nu = 0$ and $\nu = \nu_1$. The transmission band thus reaches from $\nu = 0$ to $\nu = \nu_1$. The attenuation band reaches from $\nu = \nu_1$ to ∞. The limiting frequencies are therefore $\nu = 0$ and $\nu = \nu_1$. For the sake of simplicity we shall express the frequency with the limiting value ν_1 as unity and thus put:

$$\frac{\nu}{\nu_1} = x \quad \ldots\ldots\ldots \quad (33)$$

The limiting frequencies are therefore given by $x = 0$ and $x = 1$. According to equation (17) we have for a limiting frequency:

a) $Z_1 = 0$, $Z_2 \neq 0$ or
b) $Z_2 = \infty$, $Z_1 \neq \infty$ or
c) $Z_1 = -4\,Z_2$.

[1]) Philips techn. R. 1, 272, 1936.



complete branches — T-section — Π-section — half section — reactance-diagram

Fig. 8. Low-pass filter section. Basic form: $L_1' = R'/\pi\,\nu_1$; $C_2' = 1/R\pi\,\nu_1$.

For $x = 0$ ($\nu = 0$) a) and b) are satisfied, for $x = 1$ ($\nu = \nu_1$) condition c) is satisfied. According to equation (18) we have for frequencies with infinite attenuation:

a) $Z_1 = \infty, \quad Z_2 \neq \infty$ or
b) $Z_2 = 0, \quad Z_1 \neq 0.$

These conditions are satisfied when $x = \infty$ ($\nu = \infty$).

In the previous article we have seen that the characteristics of filter sections are determined by $Z_1 Z_2$ and $Z_1/4\,Z_2$. For the sections in fig. 8 these magnitudes are expressed in the filter elements L_1' and C_2':

$$Z_1'\,Z_2' = \frac{L_1'}{C_2'} \; ; \quad \ldots \ldots \quad (34)$$

$$\frac{Z_1'}{4\,Z_2'} = -{}^1/_4\,\omega^2\,L_1'\,C_2' \quad \ldots \quad (35)$$

$Z_1'\,Z_2' = L_1'/C_2'$ is real, positive and independent of the frequency. We can therefore write:

$$Z_1'\,Z_2' = \frac{L_1'}{C_2'} = R^2 \quad \ldots \quad (36)$$

We shall soon see the physical meaning of this resistance R.

For the limiting frequency $x = 1$ we have $Z_1'/4\,Z_2' = -1$, so that:

$${}^1/_4\,\omega_1^2\,L_1'\,C_2' = 1 \quad \ldots \ldots \quad (37)$$

From equations (36) and (37) we get L_1' and C_2' expressed in terms of R and ν:

$$\left.\begin{aligned} L_1' &= \frac{R}{\pi\,\nu_1}\,; \\ C_2' &= \frac{1}{R\,\pi\,\nu_1}\,. \end{aligned}\right\} \quad \ldots \ldots \quad (38)$$

Substitution of (33) and (38) in (32) gives:

$$\left.\begin{aligned} Z_1' &= j\,2\,R\,x \;; \\ Z_2' &= \frac{R}{j\,2\,x} \;; \end{aligned}\right\} \quad \ldots \ldots \quad (39)$$

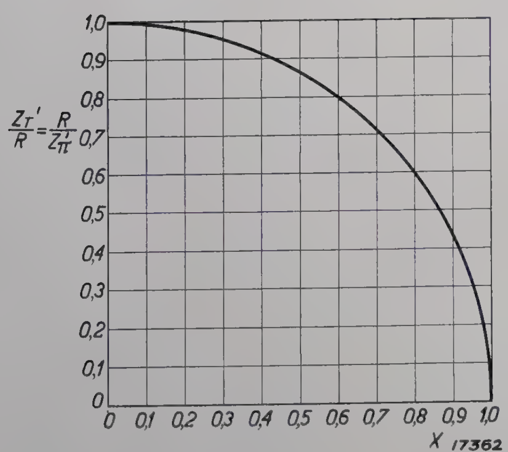


Fig. 9. $Z_T'/R = R/Z_\pi'$ plotted as a function of the frequency $x = \nu/\nu_1$ in the transmission range for the basic type of a low-pass filter.

$$\frac{Z_1'}{4\,Z_2'} = -x^2 \quad \ldots \ldots \ldots \quad (40)$$

The image impedances now follow from (9) and (12)

$$Z_T' = R\,\sqrt{1 - x^2} \;; \quad \ldots \ldots \quad (41)$$

$$Z_\pi' = \frac{R}{\sqrt{1 - x^2}} \quad \ldots \ldots \quad (42)$$

The physical meaning of the resistance R is thus the image impedance (both Z_T' and Z_π') of this filter section for $x = 0$ ($\nu = 0$). *Fig. 9* gives:

$$\frac{Z_T'}{R} = \frac{R}{Z_\pi'}$$

for these filter sections as a function of the frequency x ($= \nu/\nu_1$) in the transmission band. In the attenuation band $x > 1$ and Z_T' and Z_π' are therefore imaginary according to (41) and (42), thus conforming with the general conclusions previously reached. The value of the image impedances in the attenuation range is in most cases of no practical use.

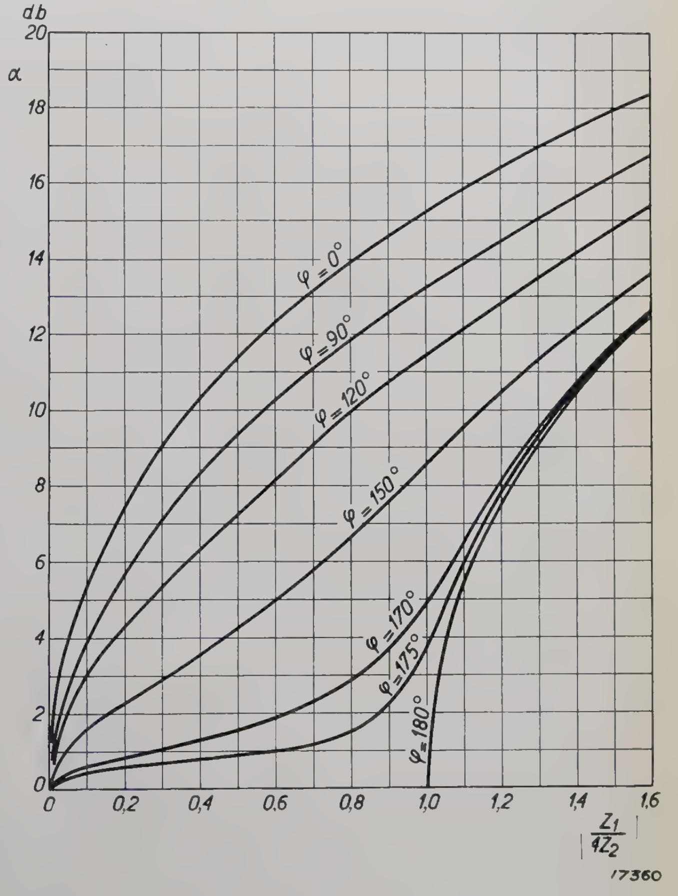


Fig. 10. Attenuation equivalent a (real part of the propagation constant T) in decibels as a function of $Z_1/4\,Z_2$ for T- and Π-sections.

$Z_1/4\,Z_2 = U + j\,V$; $\tan\varphi = V/U$

The attenuation equivalent a is determined by means of *fig. 10* in which a for the whole section

(whether of the T-form or the Π-form) is represented as a function of $|Z_2/4\,Z_2|$, for which x^2 may be substituted according to equation (40). For the half section α is half as great. α is expressed in decibels, i.e. 20 times the value found for the real part of the exponent when e^{-T} is written as a power of 10, as is almost universally the practice at the present day. We must here take the curve with the parameter $\varphi = 180$ deg. (Further reference will be made later to the significance of this parameter and the other curves in these illustrations). We see from the figure that the loss in the transmission band ($x < 1$, or $|Z_1/4\,Z_2| > 1$) is zero and in the attenuation band ($x > 1$, $|Z_1/4\,Z_2| > 1$)

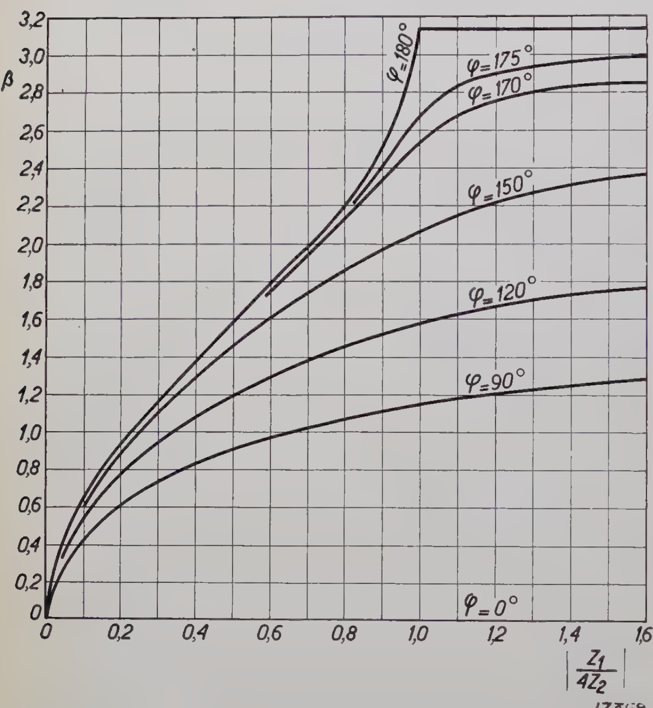


Fig. 11. Phase constant β (imaginary part of the propagation constant T) as a function of $|Z_1/4\,Z_2|$ for T- and Π-sections.

it increases from zero to ∞ as the frequency rises.

The phase constant β is obtained from *fig. 11*, where again the curve with the parameter $\varphi = 180$ deg. is the operative one. It is seen that β in the transmission band increases from 0 to π as the frequency rises and is constant in the attenuation band.

b) m_T-Transformation. Applying equations (21) and (22) to the section in fig. 8 as the basic type, we get the complete sections, the T-section, the Π-section, the half-section and the reactance diagram given in *fig. 12*. We thus have:

$$Z_1 = m\,Z_1' \;;$$

$$Z_2 = \frac{1-m^2}{4\,m}\,Z_1' + \frac{1}{m}\,Z_2' \;;$$

i.e.

$$\left.\begin{aligned} L_1 &= m\,L_1' \;; \\ L_2 &= \frac{1-m^2}{4\,m}\,L_1' \;; \\ C_2 &= m\,C_2' \;; \end{aligned}\right\} \quad \ldots\ldots (43)$$

$$\left.\begin{aligned} Z_1 &= j\,2\,R\,m\,x = m\,Z_1' \;; \\ Z_2 &= j\,2\,R\,\frac{1-m^2}{4\,m}\,x + \frac{R}{j\,2\,m\,x} = \\ &= Z_2'\,\frac{1-x^2\,(1-m^2)}{m}. \end{aligned}\right\} \quad (44)$$

(L_1' and C_2' are the elements of a fundamental type whose values are obtained from equation (38).

For the three magnitudes Z_T, Z_π and $Z_1/4\,Z_2$ which determine the characteristics of the filter section, we get from equations (23), (24) and (25) if we again put $1 - m^2 = 1/a^2$:

$$Z_T = Z_T' = R\sqrt{1-x^2} \;; \quad \ldots\ldots (45)$$

$$Z_\pi = Z_\pi'\left(1 - \frac{x^2}{a^2}\right) = R\,\frac{1-\dfrac{x^2}{a^2}}{\sqrt{1-x^2}} \;; \quad \ldots\ldots (46)$$

$$\frac{Z_1}{4\,Z_2} = \frac{a^2-1}{1-\dfrac{a^2}{x^2}} \quad \ldots\ldots (47)$$

We have already found that the transmission band, the attenuation band and the limiting frequencies are the same for the transformed type as for the fundamental type. The frequency with

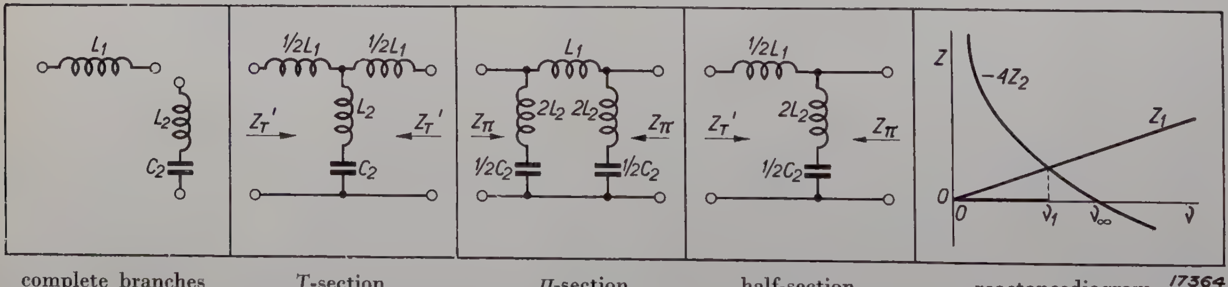


Fig. 12. Low-pass filter section. m_T-transformation: $L_1 = mL_1'$; $L_2 = \frac{1-m^2}{4\,m}\,L_1'$; $C_2 = mC_2'$.

infinite attenuation, x_∞, is the resonance frequency of Z_2, since for this frequency $Z_2 = 0$ and $Z_1 \neq 0$. For $x = \infty$, both Z_1 and Z_2 are ∞. To obtain the attenuation for this frequency, we put $x = \infty$ in equation (47) and obtain:

$$\frac{Z_1}{4\,Z_2} = a^2 - 1 = \frac{1}{1-m^2} - 1,$$

which only becomes ∞ for $m = 1$, i.e. for the basic type. In the transformed types the attenuation for $x = \infty$ ($\nu = \infty$) is thus finite. The frequency with infinite attenuation ν_∞ is obtained by putting $Z_2 = 0$ in equation (44), i.e.

$$x_\infty = a = \frac{1}{\sqrt{1-m^2}} \quad . \quad . \quad . \quad . \quad . \quad (48)$$

We have seen before that m lies between 0 and 1. It follows herefrom that x_∞ lies between 1 and ∞. By a suitable choice of m infinite attenuation can thus be obtained for any arbitrary frequency in the attenuation band.

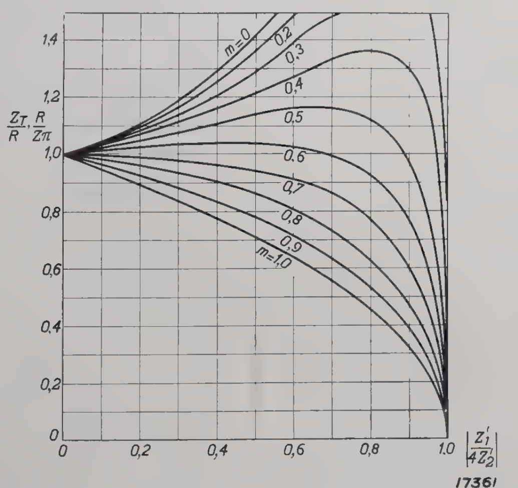


Fig. 13. $Z_T/R = R/Z$ plotted as a function of $Z_1/4\,Z_2$ for non-dissipative filters. The image impedances Z_T for the m_π-transformation and Z_π for the m_T-transformation in the transmission range are derived from this figure for all types of filter sections.

The **attenuation equivalent** α and the *phase constant* β are again determined for each given frequency from figs. 10 and 11 by means of equation (47). For $x < a$ (i.e. $x < x_\infty$) we find from equation (47) that $Z_1/4\,Z_2$ is negative and in the figures we take the curves with the parameter $\varphi = 180$ deg; for $x > a$ (i.e. $x > x_\infty$) $Z_1/4\,Z_2$ is positive and here we take the curve with the parameter $\varphi = 0$ deg.

The image impedances $Z_T = Z_T'$ and Z_π in the passing band can be found in *fig. 13*, where Z_T/R and R/Z_π are plotted as a function of:

$$\left|\frac{Z_1'}{4\,Z_2'}\right| = x^2$$

In the m_T-transformation $Z_T/R = Z_T'/R$ is indicated by the curve with the parameter $m = 1.0$, for all different values of m to be used in this transformation, while R/Z_π is to be found from the curve with the value of m used as parameter.

c) *m_π-Transformation.* Applying the equations (27) to (31) to the basic filter in fig. 8, we get the complete sections, the T-section, the Π-section, the half-section and the reactance diagram shown in *fig. 14*. We thus get:

$$\left.\begin{aligned} L_1 &= m\,L_1'\ ; \\ C_1 &= \frac{1-m^2}{4\,m}\,C_2'\ ; \\ C_2 &= m\,C_2'\ . \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (49)$$

$$\left.\begin{aligned} Z_1 &= j\,\frac{2\,R\,m\,x}{1-x^2\,(1-m^2)} = Z_1'\,\frac{m}{1-x^2\,(1-m^2)}\ ; \\ Z_2 &= \frac{R}{2\,j\,m\,x} = \frac{Z_2'}{m}\ ; \end{aligned}\right\} \quad (50)$$

$$Z_T = Z_T'\,\frac{1}{1-\dfrac{x^2}{a^2}} = R\,\frac{\sqrt{1-x^2}}{1-\dfrac{x^2}{a^2}}\ ; \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (51)$$

$$Z_\pi = Z_\pi' = \frac{R}{\sqrt{1-x^2}}\ ; \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (52)$$

$$\frac{Z_1}{4\,Z_2} = \frac{a^2-1}{1-\dfrac{a^2}{x^2}}\ ; \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (53)$$

$$\varkappa_\infty = a = \frac{1}{\sqrt{1-m^2}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (54)$$

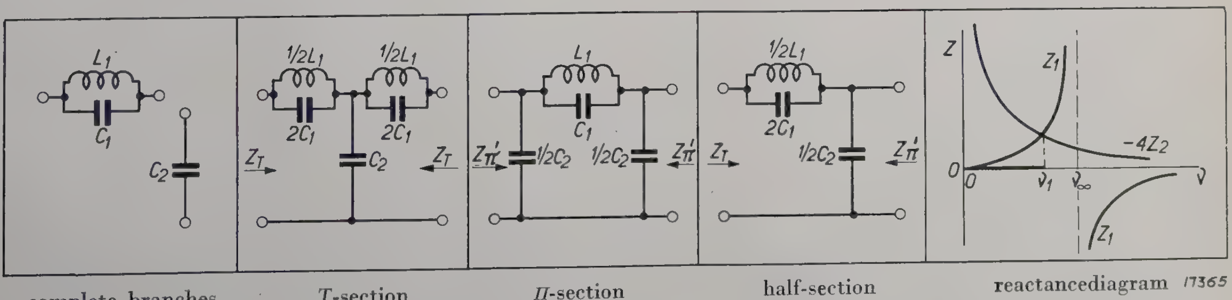


Fig. 14. Low-pass filter section. m_π-transformation: $L_1 = mL_1'$; $C_1 = \frac{1-m^2}{4\,m}\,C_2'$; $C_2 = mC_2'$.

Obviously $Z_1/4\,Z_2$ and hence x_∞, a and β for the same value of m are the same for the m_π-transformation as for the m_T-transformation.

It follows from equations (46) and (51) that Z_T/R for the m_π-transformation is equal to R/Z_π for the m_T-transformation. Z_T and Z_π are now also found from fig. 13. $R/Z_\pi = R/Z_\pi'$ is now represented independent of m by the curve with the parameter $m = 1.0$, while Z_T/R is given by the curve with the value of m used as parameter.

d) Effect of Losses in the Filter Components. Up to the present it has been assumed that the components of the filters are non-dissipative. But the coils and condensers always have a certain resistance. To determine the effect of this resistance we regard the losses in the coils as a series resistance r_L and that in the condensers as a parallel resistance R_C, writing:

$$\frac{r_L}{\omega L} = d_L, \qquad \frac{1}{R_C\,\omega\, C} = d_C.$$

We also assume that d_L is the same for all coils in the filter and d_C is the same for all condensers in the filter. Hence in the equations for the non-dissipative filter we must substitute for $j\,\omega\,L$ and $j\,\omega\,C$ the expressions:

$$r_L + j\omega L = j\omega L\left(1 - j\,\frac{r_L}{\omega\,L}\right) = j\omega L\;(1 - j\,d_L)\;;$$

$$\frac{1}{R_C} + j\omega C = j\omega C\left(1 - j\;\frac{1}{R_C\,\omega\,C}\right) = j\,\omega\,C\;(1 - j\,d_C) \qquad (55)$$

We then get for the fundamental form:

$$\left.\begin{aligned} Z_1' &= j \cdot 2\,R\,x\,(1 - j\,d_L)\;; \\ Z_2' &= \frac{R}{j\,2\,x\,(1 - j\,d_C)}\;; \end{aligned}\right\} \quad \ldots\ldots \quad (56)$$

$$\frac{Z_1'}{4\,Z_2'} = -\,x^2\,(1 - j\,d_L)\;(1 - j\,d_C) \quad \ldots \quad (57)$$

As already indicated above, the effect of the losses in the filter components on the image impedances can as a rule be neglected. The image impedances are therefore always calculated without consideration of the losses.

It follows from equation (57) that $Z_1/4\,Z_2$ is now complex, we must therefore put:

$$\frac{Z_1'}{4\,Z_2'} = U' + j\,V'\;; \quad \ldots \quad (58)$$

$$\frac{V'}{U'} = \mathrm{tg}\,\varphi' \quad \ldots\ldots\ldots \quad (59)$$

As a rule d_L and d_C are small (0.005 to 0.05). In many cases when using high-grade condensers d_C can in fact be neglected altogether. To a very close degree of approximation we can therefore write:

$$\frac{Z_1'}{4\,Z_2'} = -\,x^2\,[1 - j\,(d_L + d_C)]\;; \quad (60)$$

$$\left.\begin{aligned} U' &= -\,x^2 \\ V' &= x^2\,(d_L + d_C); \end{aligned}\right\} \quad \ldots\ldots \quad (61)$$

$$\mathrm{tg}\,\varphi' = -\,(d_L + d_C) \quad \ldots\ldots \quad (62)$$

For the transformed types we can similarly deduce $Z_1/4\,Z_2$ from the results for the non-dissipative case, by substituting $x^2\,(1 - j\,d_L)\,(1 - j\,d_C)$ for x^2. We then get:

$$\frac{Z_1}{4\,Z_2} = \frac{a^2 - 1}{1 - \dfrac{a^2}{x^2\,(1 - jd_L)\,(1 - jd_C)}} \qquad (63)$$

We now also put $Z_1/4\,Z_2 = U + j\,V$, $\tan\varphi = V/U$. In figs. 10 and 11 a and β are plotted as a function of $|Z_1/4\,Z_2|$ with φ as parameter.

In the transmission band the effect of the losses is most marked in the neighbourhood of the upper limiting frequency, where the attenuation may be fairly high owing to the losses, as may be seen from fig. 10. In the attenuation band the effect of the losses is greatest at the "frequency with infinite attenuation", resulting in the attenuation actually remaining finite. For x_∞, $x = a$ we get from equation (63) to a sufficiently close degree of approximation:

$$\frac{Z_1}{4\,Z_2} = j\,\frac{a^2 - 1}{d_L + d_C} \quad ; \ldots \quad (64)$$

$$\left|\frac{Z_1}{4\,Z_2}\right| = \frac{a^2 - 1}{d_L + d_C} \quad ; \ldots \quad (65)$$

$$\varphi = 90^\circ \quad \ldots\ldots\ldots \quad (66)$$

e) Compound Filters. It was shown in the previous article how a filter can be compounded from a number of individual sections. By connecting in series various sections of the types discussed having different values of m (also with $m = 1$, i.e. the fundamental type), the attenuation in the attenuation band can be made to satisfy specific requirements. At the points of interconnection of the sections equivalent image impedances must be contiguous; if the only sections employed are wholly T sections after m_T-transformation or Π cells after m_π-transformation, this requirement will be met. Also by inserting a half-section of the basic form T-sections can be transformed into Π-sections. It is also essential for the image impedances of the whole filter, i.e. the image impedances of the terminal sections, to be as closely equivalent as possible in the transmission band to the resist-

ances R_1 and R_2 connected across the external terminals of the filter. It is assumed that these

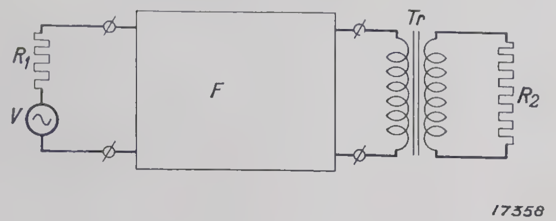


Fig. 15. Filter whose primary and secondary are terminated by the resistances R_1 and R_2 and a generator of voltage V. The ratio of the transformer Tr is $\sqrt{R_2/R_1}$. If $R_1 = R_2$ the transformer can be dispensed with.

external resistances R_1 and R_2 are real and equal to each other. If they are not real, complications occur, to which further reference must be dispensed with here. If they are different they can be made equivalent to each other by inserting a transformer (*fig. 15*). It follows from fig. 13 that for $m = 0.6$ the impedances Z_T for the m_π-transformation and Z_π for the m_T-transformation are practically independent of the frequency over nearly the whole of the transmission band. This interesting property can be employed to advantage for providing a filter with suitable terminals sections. A filter built up of T sections whether of the fundamental form or after m_T-transformation is terminated on both sides with a half-section after m_T-transformation with an image-impedance Z_π at the terminating side and $m = 0.6$; a filter made up of Π-sections is terminated with half-sections after m_π-transformation with an image-impedance Z_π at the terminating side and $m = 0.6$. *Fig. 16* gives an example of each of these two cases. At the interconnection of the sections equivalent image impedances are everywhere contiguous in the filter, and the image impedances of the whole filter are practically constant over nearly the whole of the transmission band. The values of the filter components are calculated from the equations discussed, where for R the value of the (equal) external resistances is taken.

By employing the multiple m-transformation referred to on p. 276 terminals sections can be obtained whose image impedances are still more closely constant in the transmission band. But very complex circuits are then obtained which in most cases can be dispensed with.

f) Diagrammatic Survey of the Filter Sections discussed. (*Fig. 17*). The composition and most important characteristics of the filter sections discussed are given diagrammatically in *fig. 17*. Column 1 refers to the basic form, column 2 to the m_T-transformation, column 3 to the m_π-transformation. In the first row the complete sections are given; the second row contains the values of the components of these complete sections expressed in R, ν and m. How a T-section, a Π-section and a half-section can be made up from these complete sections is shown in figs. 8, 12 and 14. The subsequent rows gives the qualitative values of Z_T, Z_π, a and β as a function of the frequency. In each picture the frequency x is represented as the abcissa such that $x = \infty$ falls in each case at the end of the axis. By adopting a similar diagrammatic method the value ∞ on the ordinate also has a finite location, except for β which is plotted linearly. In these four series the filter sections are regarded as non-dissipative. How the sketches are affected by the losses in the filter

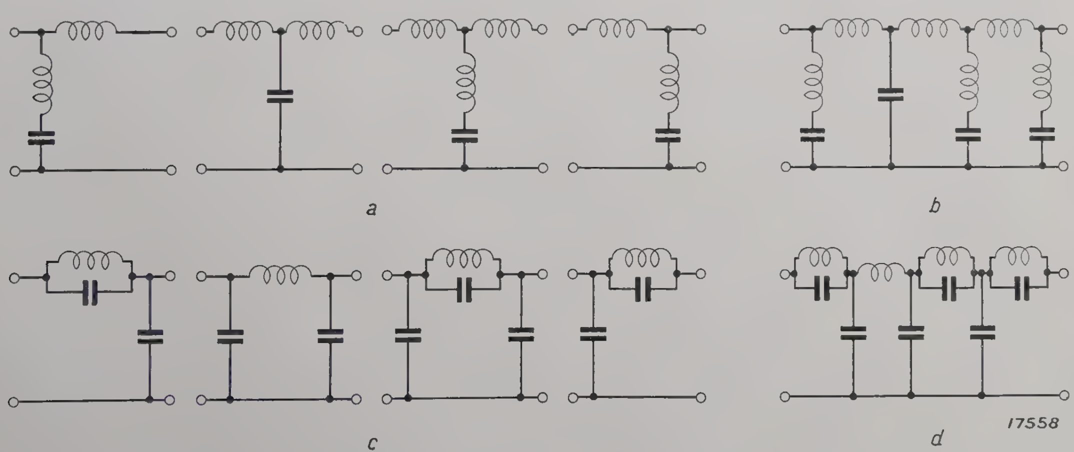


Fig. 16. Low-pass filter composed of a section of the fundamental type, a section after m-transformation with an arbitrary value of m, and two terminal half-sections after m-transformation with $m = 0.6$, giving an image impedance for the whole filter which is practically constant in the transmission band. a the individual section of T form: b these sections combined to form a filter, c the individual sections of Π form; d these sections combined to form a filter. The filters b and d are equivalent.

components may be deduced by means of the analysis given above for each particular case. In the next row $Z_1/4\,Z_2$ is given both for the ideal case ($d = 0$) as for the practical case ($d \neq 0$). By means of these equations $Z_1/4\,Z_2$ can be calculated for each frequency and the values of α and β then obtained from figs. 10 and 11. The last row of the table then gives the definitions of the magnitudes employed.

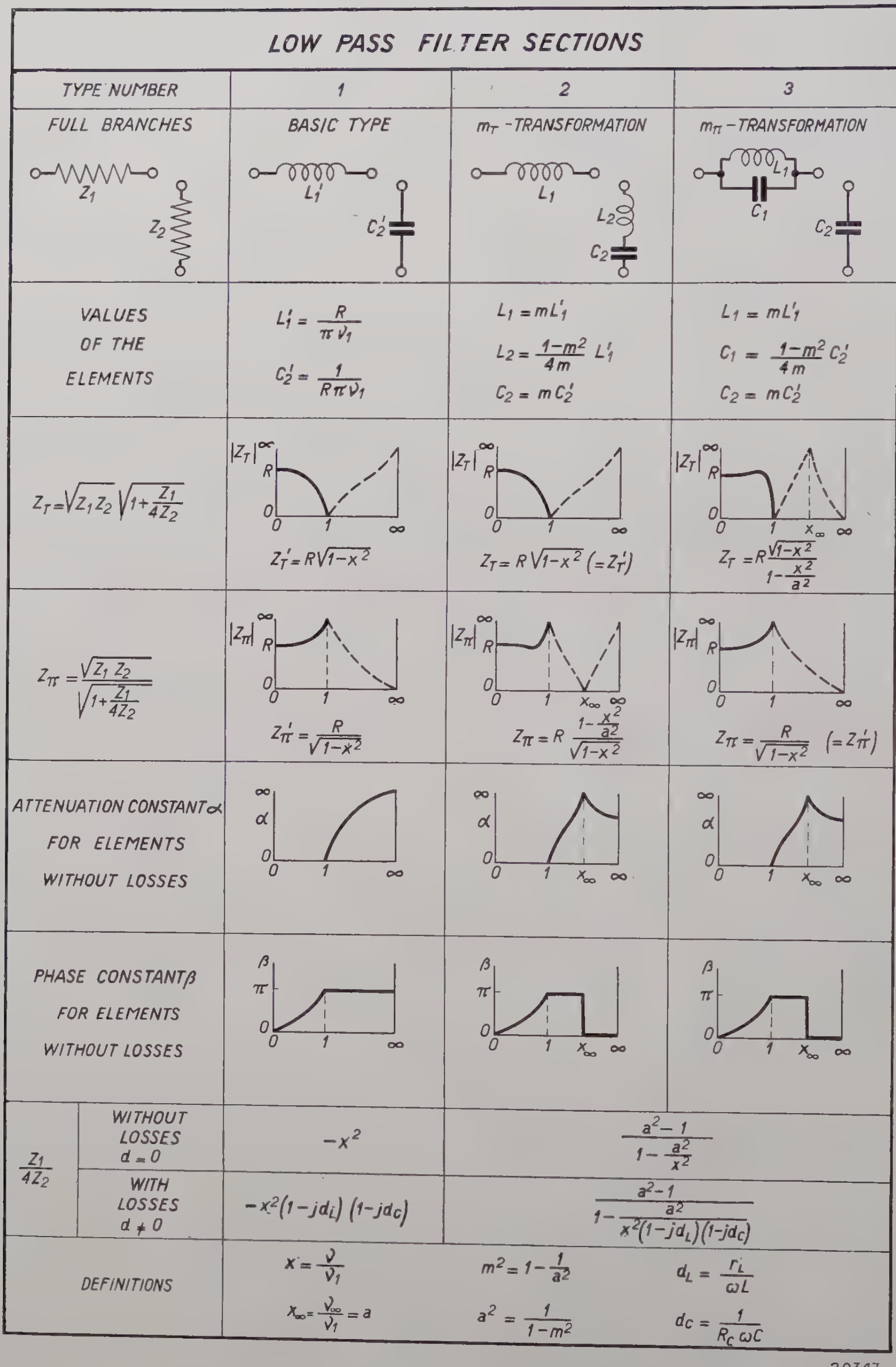


Fig. 17. Data and formulae for the construction of low-pass filter sections.

Appendix. Formulae in the article: "Electrical Filters II".

Meaning of symbols:

Z_{ao} Open-circuit impedance } Input side.
Z_{ak} Short-circuit impedance } Input side.
Z_{bo} Open-circuit impedance } Output side.
Z_{bk} Short-circuit impedance } Output side.
Z_a, Z_b Image impedances.
T Propagation constant.
α Attenuation equivalent.
β Phase constant.
I_n Primary current of the n^{th} section = secondary current in $(n-1)^{th}$ section.
Z_T, Z_π Image impedances of the T- and Π-sections respectively.
Z_1, Z_2 Complete sections.
Z_1'. Z_2' Complete sections of basic form.
m Parameter of "m-transformation".

Formulae:

$$Z_a = \sqrt{Z_{oa}\,Z_{ak}} \quad (1)$$

$$Z_b = \sqrt{Z_{bo}\,Z_{bk}} \quad (2)$$

$$\tanh T = \sqrt{\frac{Z_k}{Z_o}} \quad (3)$$

$$e^{-2T} = \frac{1-\sqrt{\dfrac{Z_k}{Z_o}}}{1+\sqrt{\dfrac{Z_k}{Z_o}}} \quad (4)$$

$$\frac{I_2}{I_1} = \sqrt{\frac{Z_a}{Z_b}}\cdot e^{-T} = \sqrt{\frac{Z_a}{Z_b}}\cdot e^{-\alpha - j\beta} \quad (5)$$

$$\frac{I_{n+1}}{I_1} = \sqrt{\frac{Z_a}{Z_{n+1}}}\; e^{-(T_1+T_2+\ldots T_n)} \quad (6)$$

$$Z_o = {}^1/_2\, Z_1 + 2\,Z_2 \quad (7)$$

$$Z_k = {}^1/_2\, Z_1 \quad (8)$$

$$Z_T = \sqrt{Z_o\,Z_k} = \sqrt{Z_1\,Z_2}\sqrt{1+\frac{Z_1}{4\,Z_2}} \quad (9)$$

$$Z_o = 2\,Z_2 \quad (10)$$

$$Z_k = \frac{2\,Z_1\,Z_2}{Z_1 + 4\,Z_2} \quad (11)$$

$$Z_\pi = \sqrt{Z_o\,Z_k} = \frac{\sqrt{Z_1\,Z_2}}{\sqrt{1+\dfrac{Z_1}{4\,Z_2}}} \quad (12)$$

$$\frac{Z_k}{Z_o} = \frac{1}{1+\dfrac{4\,Z_2}{Z_1}} \quad (13)$$

For half-section:

$$e^{-2T} = \frac{\sqrt{1+\dfrac{Z_1}{4\,Z_2}} - \sqrt{\dfrac{Z_1}{4\,Z_2}}}{\sqrt{1+\dfrac{Z_1}{4\,Z_2}} + \sqrt{\dfrac{Z_1}{4\,Z_2}}} \quad (14)$$

For T-section and Π-section:

$$e^{-T} = \frac{\sqrt{1+\dfrac{Z_1}{4\,Z_2}} - \sqrt{\dfrac{Z_1}{4\,Z_2}}}{\sqrt{1+\dfrac{Z_1}{4\,Z_2}} + \sqrt{\dfrac{Z_1}{4\,Z_2}}} \quad (15)$$

Valid for transmitting band:

$$-1 < \frac{Z_1}{4\,Z_2} < 0 \quad (16)$$

Boundaries at passing bands:

$$\frac{Z_1}{4\,Z_2} = \begin{cases} 0 \\ -1 \end{cases} \quad (17)$$

Condition for infinite attenuation:

$$\frac{Z_1}{4\,Z_2} = \infty \quad (18)$$

m_T-transformation:

$$Z_k = {}^1/_2\, m\, Z_1' \quad (19)$$

$$Z_o = \frac{Z_1'}{2\,m} + \frac{2\,Z_2'}{m} \quad (20)$$

$$Z_1 = m\,Z_1' \quad (21)$$

$$Z_2 = \frac{1-m^2}{4\,m} Z_1' + \frac{1}{m} Z_2' \quad (22)$$

$$Z_T = Z_T' \quad (23)$$

$$Z_\pi = Z_\pi'\left(1 + \frac{1\,Z_1'}{a^2\,4\,Z_2'}\right) \quad (24)$$

$$\frac{Z_1}{4Z_2} = \frac{Z_1'}{4Z_2'} \frac{m^2}{1 + \frac{1}{a^2}\frac{Z_1'}{4Z_2'}} \quad \dots\dots\dots\dots \quad (25)$$

$$0 \leqslant m \leqslant 1 \quad \dots\dots\dots\dots \quad (26)$$

m_π-transformation:

$$Z_1 = \text{parallelconnection of } mZ_1' \text{ and } \frac{4m}{1-m^2} Z_2' \quad (27)$$

$$Z_2 = \frac{1}{m} Z_2' \; ; \quad \dots\dots\dots\dots \quad (28)$$

$$Z_\pi = Z_\pi' \; ; \quad \dots\dots\dots\dots \quad (29)$$

$$Z_T = Z_T' \frac{1}{1 + \frac{1}{a^2}\frac{Z_1'}{4Z_2'}} \; ; \quad \dots\dots\dots\dots \quad (30)$$

$$\frac{Z_1}{4\,Z_2} = \frac{Z_1'}{4Z_2'} \frac{m^2}{1 + \frac{1}{a^2}\frac{Z_1'}{4Z_2'}} \quad \dots\dots\dots\dots \quad (31)$$

A SURVEILLANCE SYSTEM USING INFRA-RED RAYS

By A. L. TIMMER and A. H. VAN ASSUM.

Summary. Description of a surveillance system with infra red alternating light intensity, which works over a distance of 425 metres. In addition to the light source a foto-electric cell and a two valves amplifier is used.

Introduction

At the present time it is becoming increasingly the practice to entrust the protection and surveillance of rooms containing valuable objects no longer to human attendants, but to automatic alarm systems which become actuated immediately an unauthorised person enters the protection area. The advantage of an arrangement of this type is that surveillance is continuous and that if required the competent public authorities, such as the police, can be directly warned of any intrusion, etc. The close surveillance offered by these systems is particularly useful and desirable, for instance, on strong rooms of banks, valuable collections in museums, shop premises, etc.

A reliable and efficiently alarm system must satisfy the following requirements:

1) It must not be capable of being easily rendered inoperative.
2) It must give an alarm on any interference with its normal state of preparedness (e.g. a failure of the current supply).
3) It must not be recognised as an alarm system.
4) It must not be subject to interference or put out of action by normal activities and operations in the vicinity.

Various mechanical protective arrangements, such as door contacts or step contacts, are naturally quite practicable, but important advantages are offered by a method using invisible rays which on being intercepted in any way release an alarm system. Fundamentally the method depends on the operation of a photo-electric cell, which furnishes a current as long as infra-red radiation falls on it. After amplification this very weak current can be used for controlling an alarm system.

In the simplest form of such a system the photo-electric current is used directly for energising a relay. The current generated is however only of the order of a few micro-amperes, as may be gathered from the following example. If a glowlamp of say 25 candles is used as a light source, the total luminous flux radiated will be about 250 lumens. When a photo-electric cell with a window opening of e.g. 20 sq. cm is placed about 1 m from the lamp, the light falling on the cell will be:

$$\frac{20}{4\pi 100^2}\, 250 \approx 0.04 \text{ lumen.}$$

A vacuum cell is employed which for white light has a sensitivity of approx. 25 micro-amps per lumen so that a current of about 1 micro-amp is generated. This extremely weak current can be intensified by inserting a lens between the light source and the photo-electric cell (*fig. 1*). If for this purpose a lens of 25 cm focal length and 10 cm diameter is used and the distance between the cell and the light source is made only so great that the image of the incandescent coil still falls completely within the cell window, then the whole of the light collected by the lens will fall on the cell.

The coil covers roughly a square of 2 mm side, while the cell window is a circle of 5 cm diameter. The filament must then be placed 26 cm in front generated is 350 microamps, which is still too small. We are employing visible light in this example, which therefore does not satisfy condition 3) above.

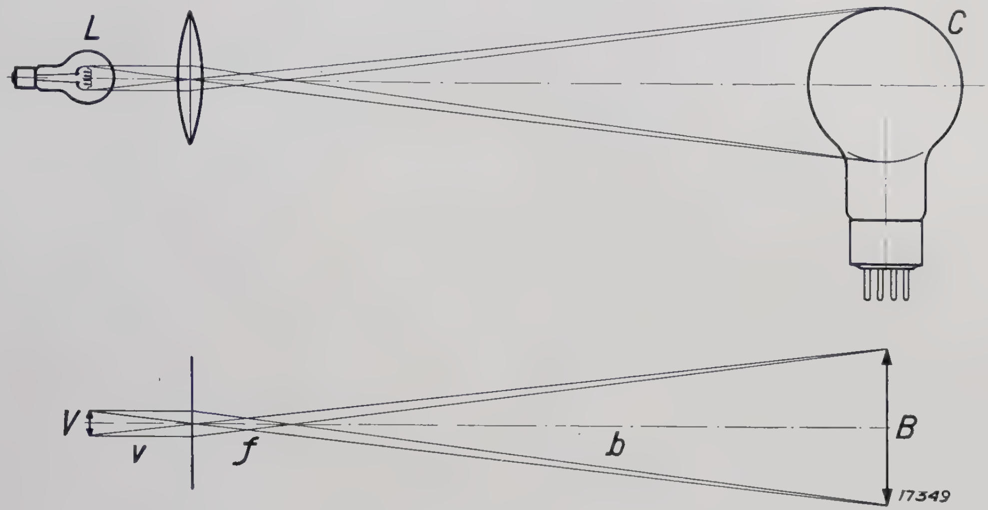


Fig. 1. The image of the incandescent filament of a glowlamp L is produced in such a way that it exactly fills the aperture of a photo-electric cell C. In the lower half of the figure V is the size of the incandescent coil, v its distance from the lens, f the focal length of the lens, b the distance of the cell from the lens, and B the size of the image V on the cell.

of the lens, and the image is produced 460 cm behind the lens, so that a space of 4 m wide can be readily kept under surveillance.

Although the lens throws a much greater portion of the spherically-radiated light on the photo-electric cell than would be incident thereon without a lens, even with this arrangement only 2.32 lumens of the 250 lumens radiated will reach the cell, the absorption losses in the lens being still left out of account. The photo-current is then 58 micro-amperes. It is not a simple matter to construct a relay responding to this small current, while moreover the space of $4^1/_2$ m wide controlled is not particularly large. If in place of a vacuum cell a gasfilled cell is used which is six times as sensitive, but also critical in adjustment, the electric current

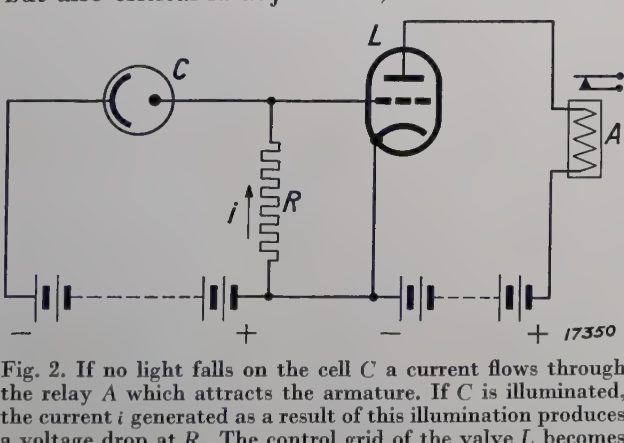


Fig. 2. If no light falls on the cell C a current flows through the relay A which attracts the armature. If C is illuminated, the current i generated as a result of this illumination produces a voltage drop at R. The control grid of the valve L becomes negative, and the anode current through A is reduced so that the armature is released.

Since the photo-electric cell under consideration is however fairly sensitive to infra-red rays, the light beam can be rendered invisible by passing it through a glass plate which allows only the infra-red rays to pass through (infra-red filter). This adaptation reduces the photo-current to about a third. In order to be able to operate a relay it has thus been found necessary to amplify the photo-current.

The Amplifier

A simple circuit for amplifying the photo-electric current is shown in *fig. 2*.

The current generated in the photo-electric cell C by illumination is passed through a resistance R, which is connected to the grid and cathode of the amplifying valve L, so that the voltage of the grid is negative with respect to the cathode. The method of operation is then as follows: No current passes through the resistance R when no illumination falls on the cell. The grid of the valve L is then at the same potential as the cathode, and a definite anode current is circulating which maintains the attraction of the armature of the relay A. When the cell is illuminated the grid becomes negative, and as a result the anode current diminishes, thus releasing the relay armature. In this position the whole system is therefore in the "safe" setting. If the beam of light is interrupted, the current through the relay rises, the armature is attracted and an "alarm" arrangement can be operated.

This method of operation obviously does not satisfy the second condition enumerated above. Any failure or interference in the amplifier remains undetected, since the relay current is then zero and the armature is hence not attracted. This shortcoming can however be readily overcome by

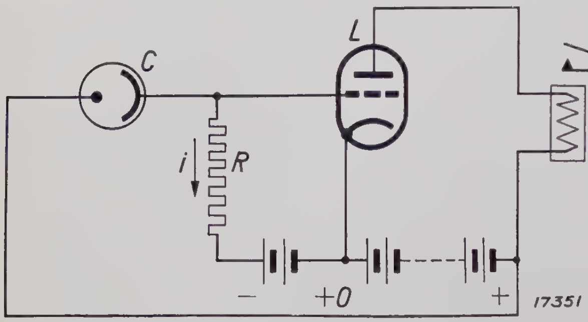


Fig. 3. If no light falls on C a very weak current flows through A which causes no other component to operate. If C is illuminated then, contrary to fig. 2, the grid of L becomes more *positive*, since here the current from C flows through R in the *opposite* direction; the current through A increases and may cause the attraction of the armature.

using the circuit shown in *fig. 3*, where the grid of the amplifying valve L has a negative grid bias, so that a small feed current flows through the relay A which does not actuate the latter. Since the photo-electric cell is connected in the opposite way to that shown in fig. 2, the photo-current through the resistance R generated on illumination will reduce the negative grid bias, so that the anode current rises and the relay operates. If the system is in increased by using a more powerful source of light, but this introduces the need for greater amplification; one valve is not sufficient for this purpose and several have to be used.

The fundamental circuit of the apparatus evolved in this Laboratory is reproduced in *fig. 4*. It will be seen that a condenser has been inserted between the photo-electric cell and the grid of the first amplifying valve. This has been done for the following reason: The circuits in figs. 2 and 3 are fundamentally those for D.C. amplifiers. It is, however, difficult without complicated precautions to obtain a D.C. amplifier with more than one stage, while on the other hand the construction of a multi-stage amplifier for A.C. is very simple. Fig. 4 is thus a circuit for an A.C. amplifier, so that it is necessary to furnish the cell with A.C. also.

Two methods can be used for generating alternating current:

1) Alternating voltage can be passed to the anode of the cell.

2) The cell can be illuminated with an intermittent or fluctuating light.

The second method is naturally the more advantageous. The apparatus no longer responds to a continuous beam of light, so that one cannot walk through the beam and direct a beam from a pocket lamp on to the cell as a substitute for the screened light. For this reason the second method was selected.

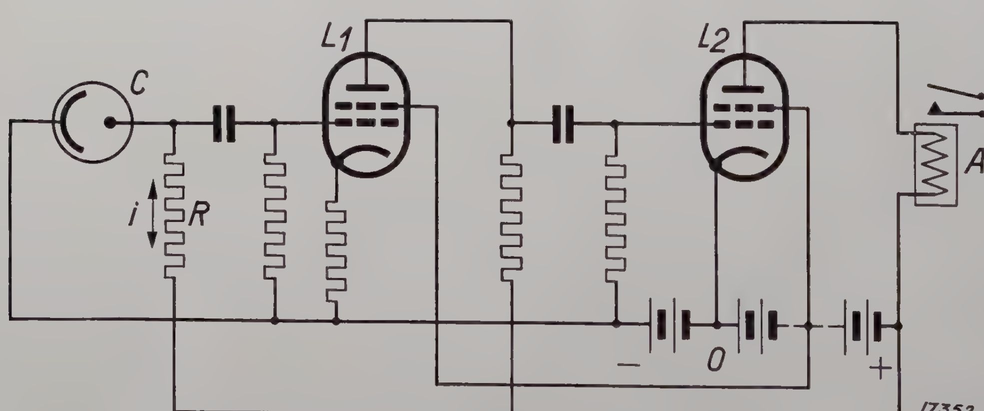


Fig. 4. The intermittent illumination system. Light of fluctuating intensity falls on the photo-electric cell C; *inter alia*, an alternating voltage is thus generated across R. This voltage is amplified by L_1 and is then applied to L_2, whereupon the current through the relay A increases, as shown in fig. 6.

the "safe" setting, then contrary to the circuit in fig. 2 current flows through the relay such that the armature remains attracted. Any interference of whatever nature will then release the alarm system. The width of the area protected can be

The fluctuating light is generated in the following way: A steel spring is substituted for the armature in a magnetised coil (such as that from a loudspeaker) which is energised by alternating current. A small disk is attached to the spring at its free

end. On connecting the coil to the A.C. mains supply the disk will vibrate with a frequency of 50 times per second (*fig.* 5). This arrangement is

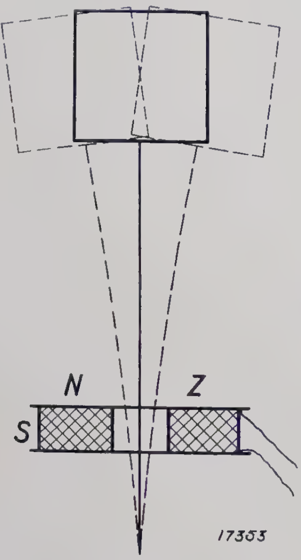


Fig. 5. Oscillating spring for generating the intermittent beam. 50-cycle alternating current is passed through the coil *S*, so that the spring is set in vibration with the aid of the horseshoe magnet with poles *N* and *Z*.

set up in the beam between the glowlamp and the lens in such a way that the disk, when at rest, just bisects the beam of light falling on the lens. In this way the beam can be entirely cut off or given a free passage by a minimum deflection of the spring. One might be inclined to employ resonance phenomena, i.e. make the natural frequency of the spring equal to the A.C. frequency, in order to obtain a large deflection with a small power. This method cannot however be used satisfactorily since then a small variation in frequency will immediately result in a marked diminition of the deflection. The natural frequency must exceed the frequency superposed on it, as otherwise the spring would vibrate about a node.

In this way the photo-electric cell receives an intermittent beam of light so that on a voltage drop in *R* an alternating voltage is obtained at the grid of the first amplifying valve. After amplification this voltage is impressed on the grid of the second valve, which acts as an anode rectifier and whose anode current therefore increases with increasing (alternating) voltage at the grid. The grid of L_2 has a negative bias of such a value that a very weak anode current flows (*fig.* 6). If alteinating voltage is now applied to the grid the anode current as shown in the figure will become pulsating; the pulsations are not however registered if measured by a moving coil instrument which at a sufficiently high frequency of pulsation indicates the mean current. This anode current is employed for actuating the alarm relay.

The currents at which the relay attracts or releases

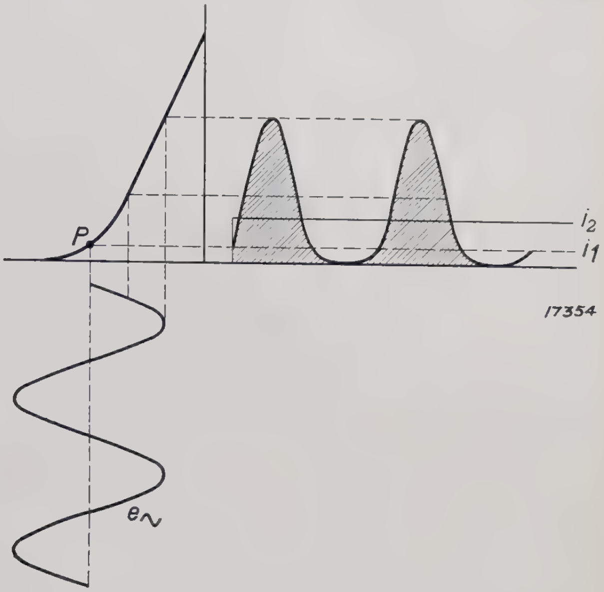


Fig. 6. In the absence of alternating voltage at the grid the amplifying valve operates at the point *P* of the characteristic (current intensity i_1). If an alternating voltage is applied to the grid a pulsating anode current with an average value of i_2 is obtained.

the armature are determined by the dimensions. From the characteristic of the rectifier, i.e. from the variation of the anode current as a function of the grid alternating voltage, the voltage required at the grid can be found so that the relay attracts its armature. The rest current which flows when no alternating voltage is present, i.e. when the light beam is cut off, must therefore be a little smaller than the current at which the armature is released (see *fig.* 7).

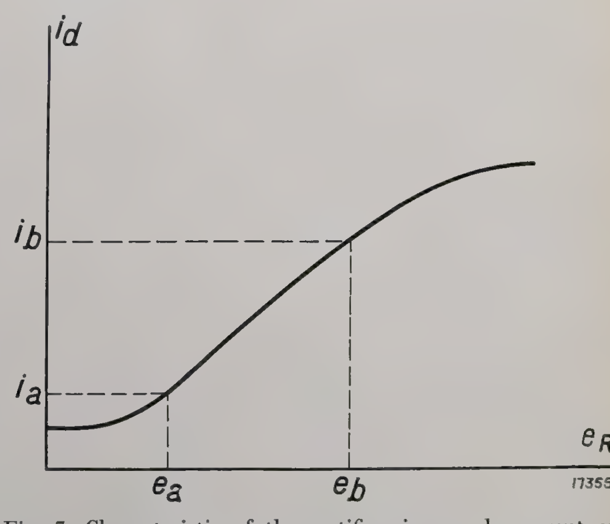


Fig. 7. Characteristic of the rectifier, i.e. anode current of the rectifier (which therefore flows through the relay *A*) as a function of the alternating voltage at the resistance *R* of fig. 4. At the current i_b the relay armature is attracted; at i_a it is released.

Sensitivity of the system

The sensitivity of the system is mainly determined by the current sensitivity of the relay, which in its turn is governed *inter alia* by the windings on the relay core. The power of a relay is determined solely by the product of the current intensity and the number of turns, so that up to a point the sensitivity of the relay can be raised by increasing the number of turns and reducing the diameter of the wire. Since the photo-electric cell must generate such a current that the amplifier can furnish the difference between the currents at which the relay armature is attracted and released, it is evident that these currents will preferably be made small since the ratio between them is constant.

It has been found possible to wind a relay having a "response current" of 0.6 mA and a "release current" of 0.2 mA. To obtain this current difference a grid alternating voltage of 0.015 volt is required at the first amplifying valve. The photo-electric cell must therefore furnish 0.015 μA (through an impedance of 1 megohm). This is the effective value, the peak value is $\sqrt{2}$ times greater. The light however fluctuates from zero to a maximum, and the curve of the intermittent light must be compared with the "zero line" A, as shown in *fig. 8*. This indicates that the peak value of the current which the cell must furnish is:

$$2 \cdot 0.015 \cdot \sqrt{2} = 0.042 \ \mu\text{A}.$$

When using a gasfilled photo-electric cell whose sensitivity for white light is approx. 150 μA per lumen, the 0.042 μA required would need an intensity of 0.00028 lumen of white light. With infra-red rays the sensitivity is however three times smaller, so that then 0.00084 lumen (expressed as white light) must impinge on the photo-electric cell.

Distance of Surveillance

To calculate the length of beam corresponding to an intensity of 0.00084 lumen at the cell window, it must be remembered that over this great distance the whole of the light emerging from the lens no longer falls on the photo-electric cell; the size of the image of the lamp coil is on the other hand a multiple of the cell window (*fig. 9*). In this case the amount of incident light is inversely proportional to the square full distance of the light source. Since the focal length f, the size V of the lamp coil and the quantity of light L falling on the lens are fixed, and also the amount of light l required for illuminating the cell cannot be improved in the particular construction adopted, the length of the beam b between the lens and the cell can only be increased by enlarging the surface A^2 of the cell. The photo-electric cell must receive a minimum of

$$l = \frac{A^2}{B^2} \cdot L = \frac{A^2 f}{b^2 V^2} L$$

which gives for the permissible distance of the photo-electric cell:

$$b = \frac{f}{V} \cdot \sqrt{\frac{A^2 L}{l}} \, .$$

The magnitude A^2, the operative area of the cell, can in fact be further increased. For if the cell is placed at the focus of a parabolic mirror, the effective surface of the cell will be equal to that of the mirror.

The above-mentioned magnitudes have the following values in our apparatus:

$$\begin{aligned} f &= 25 \text{ cm}, \\ V &= 0.2 \text{ cm}, \\ A^2 &= 200 \text{ sq cm}, \\ L &= 2.32 \text{ lm (see above)}, \\ l &= 0.00084 \text{ lm} \end{aligned}$$

so that for infra-red light the distance of surveillance can be:

$$b = \frac{0.2}{25} \sqrt{\frac{200 \cdot 2.32}{0.00168}} = 93000 \text{ cm}$$

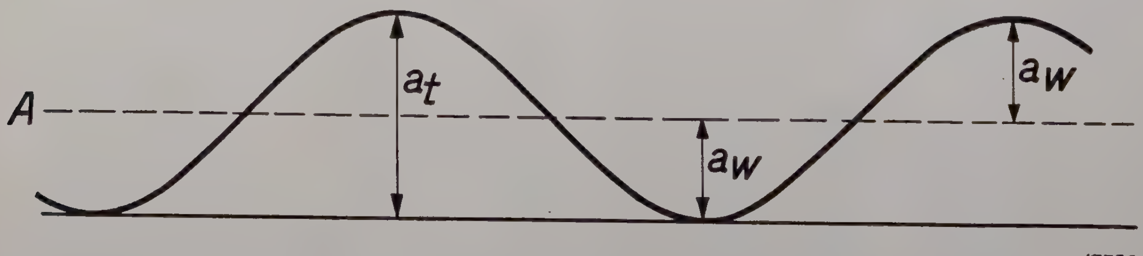


Fig. 8. Fluctuation of the intermittent beam as a function of the time. The average value is represented by the line A and is a_w. The curve may be regarded as made up of two components, viz., a D.C. component with the value a_w and an A.C. component with the amplitude a_w.

In practice the attainable length of beam is smaller since absorption losses must also be taken in consideration. A more comprehensive system of surveillance with rays will in fact require a larger number of mirrors, e.g. for reflecting the beam of light to and fro. The lens and the parabolic mirror referred to above also absorb light. If five plane mirrors are used and each optical unit absorbs 20 per cent of the light incident on it, then the quantity of light L must be multiplied by a factor $(0.8)^7 = 0.21$.

The maximum path of surveillance is then:

$$b' = 93000 \sqrt{0.21} \approx 42500 \text{ cm}.$$

The apparatus could therefore be used for surveillance over a distance of 425 m.

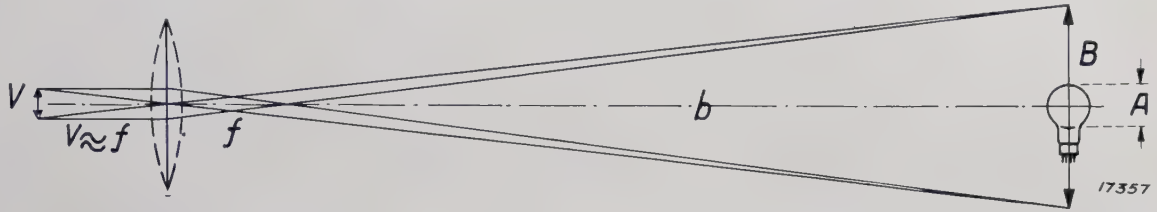


Fig. 9. Layout of a surveillance system in which the window A of the photo-electric cell is considerably smaller than the image B of the lamp coil.

Advantages and Disadvantages

One disadvantage of all systems run from alternating current mains is that any failure in the supply immediately causes a false alarm to be given. The apparatus will also give an alarm when a failure or defect develops in one of the components; yet, according to the point of view, this can also be regarded as an advantage.

The principal advantage of the system is the fact that the beam of light is itself a fluctuating magnitude. A second and less important advantage is that, owing to the provision of the parabolic mirror which concentrates all incident rays at its focus, a screen with a small hole can be placed at this level at the focus itself. Extraneous light rays impinging at an angle, emanating from the general illumination or from passing light sources and concentrated next to the actual focus, do not then reach the photo-electric cell which is therefore screened against these rays. This renders interference with the apparatus by means of a light source with the same characteristics extremely difficult, since the direction of incidence of the rays has also to be very accurately adjusted.

THE ELECTRON MICROSCOPE AS AN AID IN METALLOGRAPHIC RESEARCH

By W. G. BURGERS and J. J. A. PLOOS VAN AMSTEL.

Summary. The crystalline structure of a metallic surface heated to a high temperature can be registered by employing thermo-electronic emission of the metal utilising an electron beam. For this purpose in a cathode ray tube of suitable construction the electrons emitted from the metal surface must be focussed on a fluorescent screen in the tube by means of electrical or magnetic fields.

This article describes a suitable tube for this purpose and also discusses the activation process which must be applied to the metal under investigation, in order to raise its electron emissivity to such a level that a "visible" fluorescence is obtained. In conclusion it is shown that the emission and etched diagrams are in substantial agreement.

Investigation of Crystalline Structure by Etching

To bring out the crystalline structure of a metallic surface, the usual method adopted in metallography is to polish the surface of the test specimen under examination and then to etch the surface with a suitable chemical reagent. Owing to their anisotropic structure the crystallites are not uniformily attacked by the etching medium, and certain atomic surfaces are thus subjected to a more intense action than others, such that the crystallites acquire a tiered or stepped surface. This result is shown in *fig. 1*, which illustrates diagrammatically a section drawn perpendicularly through the etched surface (the depth of the step is of the order of several microns). Since the orientation of the crystal lattice is quite abrupt on passing from one crystallite to another, the same will also apply to the direction of the steps. If therefore a beam of light is directed against the surface at a specific angle of incidence, the rays will be reflected in different directions by the different crystallites such that when viewed from a certain direction the crystallites will appear with unequal brightnesses. This phenomenon is shown clearly in *fig. 2* for an aluminium plate which is composed of comparatively large crystals and which has been etched with hydrofluoric acid and aqua regia.

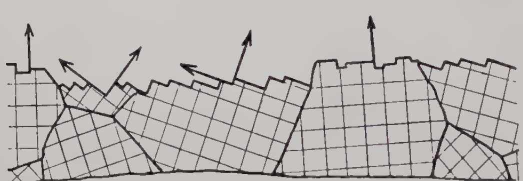


Fig. 1. *) Reflection of incident light from an etched metal surface (diagrammatic). This illustration shows a section perpendicular to the surface of the etched specimen. The thick lines indicate the boundaries of the various crystallites, and the thin lines the position of the atomic lattice in each crystallite.

*) This illustration is taken from: G. Sachs, Z. Metallk., **17**, 299, 1925.

It is obvious that etching at room temperature can only reveal the crystalline structure existing at that temperature, and that to investigate the structure obtaining at higher temperatures the specimen must be etched in the hot state. Although this can indeed be done [1]) the requisite procedure is cumbersome and difficult.

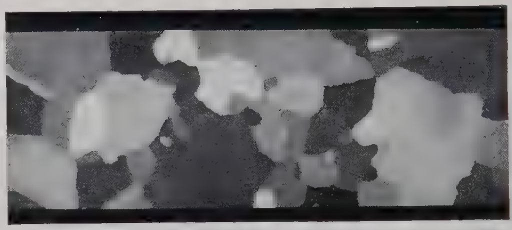


Fig. 2. Etched aluminium sheet composed of large crystals (half natural size).

Investigation of the Crystalline Structure with an Electron Beam

As already indicated in a previous issue of this Review [2]) the crystalline structure of a metallic surface at high temperatures can also be investigated by means of a beam of electrons.

The practicability of such socalled electron-optical representation depends on the following two fundamental principals:

a) The emission of electrons of metals at a hot temperature is determined by the composition of the metallic phase and for a specific composition by the surface of the crystal lattice through which the electrons emerge. This latter factor applies particularly following activation (see section below).

b) If in a vacuum tube an electron-emitting cathode of suitable form is used, then by employing suitable electrical and magnetic fields it is possible to

[1]) Thus e.g. in an investigation by A. E. van Arkel and P. Koets (Z. Phys., **41**, 701, 1927) Iron was etched with chlorine gas at a temperature above 900 ° C.

[2]) G. P. Ittmann, Philips techn. Rev. **1**, 33, 1936.

concentrate all electrons emitted from a specific point of the cathode on to a given point of a screen situated at a given distance away. The luminous pattern obtained on the fluorescent coating of this screen will then correspond point for point to the distribution of intensity over the emitting cathode surface. As may be gathered from the previous article in this Review, a magnification or reduction of the image of the structure can be realised according to requirements. Magnification is employed in the "electron microscope" in order to obtain a maximum size of image on the cathode surface. If this surface forms part of the specimen under examination, then in view of the differences in emissivity referred to above the different crystallites will be distinguishable from each other by differences in brightness on the fluorescent screen. The emission diagram obtained in this way closely resembles that obtained by etching the surface.

The first study of metallographic problems by the electron-optical method outlined above was carried out by Brüche and his collaborators during investigations in the Research Institute of the A. E. G.[3]) Investigations in similar lines[4]) have also been carried out in this Laboratory. Some results of this work will be described in two articles to show what has been achieved in this direction. In this, the first article, discussion will be devoted to the experimental method adopted, while the second article will deal in detail with the application of the method to a specific example.

Experimental Procedure

The experimental problems entailed fall into two groups:

1) Construction of the cathode-ray tube, and
2) Preparation of the metallic surface to be used as cathode.

Construction of the Cathode Ray Tube

The design and construction of the cathode-ray tube depend on the magnification required. With the comparatively low linear magnification of 15 to 25 employed in this Laboratory, the most practicable method was to focus the electrons by means of a magnetic field. A number of investigators[5]) have published constructional data for tubes of this type, and the tube employed by us, shown diagrammatically in *fig. 3*, was designed on the basis of these data. It consists of a glass cylinder *a* about 45 cm long and 6 cm wide, which is closed at one end by a flat glass plate *b*. At the other end there is a ground connection for the union with a tube holder *c* in which the metal testpiece *d* to be used as cathode is fixed; the specimen is adjustably mounted on two nickel poles. One of the nickel poles carries a brass cap *e* with an aperture at the centre. A brass cylinder *f* located in the glass cylinder *a* serves as anode.

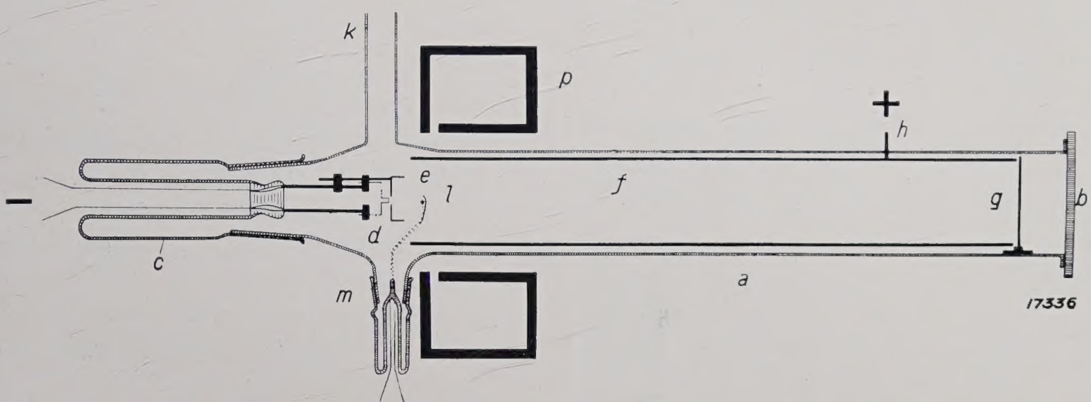


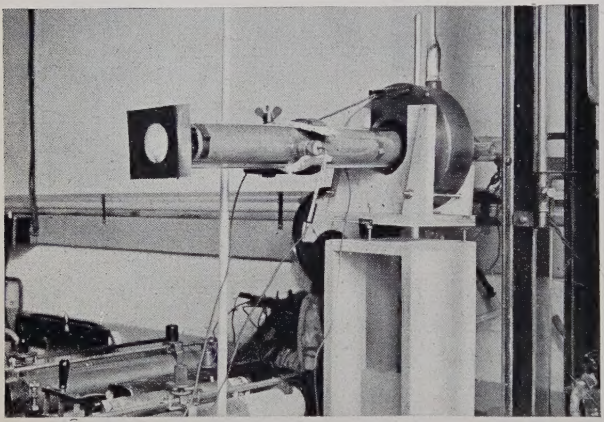
Fig. 3. Cathode ray tube with magnetic focusing for the investigation of metallic surfaces. *a* Cylindrical glass tube (length approx. 45 cm, diameter approx. 6 cm). *b* Plane glass plate. *c* Ground connection securing the cathode. *d* Cathode, made of a rolled strip of the metal under investigation. *e* Brass cap in front of cathode. *f* Anode, a wide brass cylinder. *g* Fluorescent screen. *h* Anode pole. *k* Connection for vacuum pump. *l* Tungsten coil for depositing the activating coating on the cathode. *m* Ground connection. *p* Magnet coil enclosed in mild steel sheath (internal diameter approx. 8 cm, external diameter approx. 20 cm, height approx. 6 cm).

[3]) See in particular the work by E. Brüche and O. Scherzer, Geometrische Elektronenoptik (Julius Springer, Berlin, 1934). Some new work at this laboratory will be referred to in the course of this and subsequent articles.

[4]) W. G. Burgers and J. J. A. Ploos van Amstel, Nature, **136**, 721, 1935.

[5]) M. Knoll, F. G. Houtermans and W. Schulze, Z. Phys., **78**, 340, 1932.
J. Pohl, Z. techn. Phys., **15**, 579, 1934.

At the end of the brass cylinder is the fluorescent screen *g*, usually coated with blue-fluorescing calcium tungstate (for making photographic exposures). The connection to the anode is passed out at *h*. The tube *k* connects up with a vacuum pump. By means of a tungsten coil *l* in a small tube holder any suitable substance, such as barium carbonate (if necessary produced by decomposition), can be deposited on the cathode to activate the latter. By means of the ground joint *m* the coil can be turned through a right angle after the material has been deposited, so that it no longer lies between the cathode and the fluorescent screen (as shown in the figure). Finally, *p* is a coil acting as a "magnetic lens" and which except for a slot several millimetres wide, is completely covered with mild steel to a depth of about 5 mm, as described by Ruska and Knoll. *Fig. 4* gives a general view of



17337

Fig. 4. View of experimental apparatus; the cathode ray tube, viewing window and enclosed magnet coil can be easily picked out.

the whole apparatus, the cathode ray tube and the "magnetic lens" being easily picked out. With a tube of this type diagrams subject to very little distortion can be readily obtained. Naturally to ensure good diagrams at a given anode voltage (with respect to the cathode which is earthed in this arrangement) the current through the magnet coil must be of such a value that the rays can be sharply focussed on the fluorescent screen. The optimum current intensity through the magnet coil and the optimum anode voltage depend on the emissivity of the cathode and also on the relative positions (cf. fig. 3) of the surface of the cathode *d*, the brass cap *e*, the magnet coil *p*, the brass anode *f*, and the fluorescent screen *g*. The voltages employed in our apparatus were of the order of 3000 to 6000 volts when about 1 A current was passed through the magnet coil (2000 ampere-turns).

To obtain a sharply-defined image the voltage and the current intensity must be maintained sufficiently constant. The constant voltage was supplied from a suitably-rated anode voltage unit [7]) and the constant current derived from an accumulator. Naturally the cathode ray tube as a whole had also to be adequately protected against vibration, etc.

Preparation of the Metallic Surface to be used as Cathode

Shape of the cathode

It was found that a plane cathode located perpendicular to the axis of the tube gave an image of satisfactory definition on the fluorescent screen. We employed the metal under examination in the form of a rolled strip about 2.5 mm wide and 0.1 mm thick, the shape of which is shown in fig. 3*d*. Only the front position (a small square of about 2.5 mm side) served as the actual cathode surface for which a diagram was obtained. This surface was polished [8]) and set up perpendicular to the axis of the tube immediately behind the aperture approx. 5 mm wide, in the brass cap *e*.

Activation of the Cathode

Frequently the emission of electrons from metals at temperatures at which e.g. a transformation is to be observed, is far too small to give fluorescent images of sufficient intensity for visual observation or photographic registration. It then becomes necessary to "activate" the surface of the metal, i.e. to raise its emissivity. Such activation can be realised by coating the surface with a layer of electro-positive atoms, as of barium, strontium or caesium.

As a result of such activation the aggregate emissivity of the metal is very considerably increased. But apart from this effect, an intensified contrast in the emission pattern can frequently

---

[6]) E. Ruska and M. Knoll, Z. techn. Phys., **12**, 448, 1931. In this way the magnetic field is concentrated mainly in a plane perpendicular to the axis of the cathode ray tube, permitting the ampere-turns required to obtain a given "refractive action" to be reduced. Cf. also M. Knoll and E. Ruska, Z. Phys., **78**, 318, 1932.

[7]) The anode voltage unit employed by us gives a maximum output of 20 watts. The energy taken from it is however much smaller, since the anode current is normally less than 0.1 mA.

[8]) Inequalities of the surface (as a result of deep etching), which affect the potential distribution in the immediate neighbourhood of the cathode, render the focusing action of the electrical and magnetic fields difficult and should be avoided.

[9]) Compare J. H. de Boer, Electron emission and adsorption phenomena (Cambridge 1935).

also be obtained, since the different planes in the crystal lattice adsorb varying amounts of electro-positive atoms so that the differences in their emissivities are intensified.

Activation may be performed in several ways, e.g. by coating the metal surface with an aqueous solution of barium azide or, with the aid of the tungsten coil *1* in fig. 3 which is suitably coated with barium or strontium carbonate, by depositing on the metal surface metallic barium or strontium or the oxides of these metals and then submitting the specimen to a specific, frequently complex, heat treatment, usually consisting of strongly heating the metal surface to different temperatures, with or without the simultaneous applications of the anode voltages.

The choice of activator depends *inter alia* on the temperature at which observations of the crystal structure are to be made. If this temperature is comparatively high, an activating atomic layer should be sought which does not volatilise too readily from the surface of the cathode. For observations at low temperatures activation with the most powerful electro-positive atoms is necessary, thus Schenk[10]) has obtained good results with caesium already at 400 °C. The emission of electrons from a metal can also be induced by photo-electric means by irradiating the surface with ultra-violet light. Using this method, diagrams of the crystalline structure can already be produced at room temperature[11]).

The series of photographs shown in *fig. 5* indicate the changes visible during the activation process. These photographs relate to an iron strip activated with strontium carbonate and represent various stages of the activation process[12]).

Immediately after vaporisation a more or less uniform emission is observed (*a*) at a comparatively low temperature (approx. 800 to 900 ° C.), such emission revealing no crystalline structure. The temperature is then raised, e.g. to 1010 ° C., whereupon the emission slowly decays (*b*-*c*), until eventually[13]) it disappears altogether (*d*). The temperature of the cathode is then again reduced, as a result of which emission recommences (*e*-*i*) and spreads visibly over the surface.

The emission now obtained reveals the crystalline structure of the cathode surface. *Fig. 6* enables a comparison of an electron-optical image (*a*) with the photograph of the etched cathode (*b*) taken immediately after. It is seen that the emission and etched diagrams are practically identical. The small differences observed are due to the fact that the emission diagram corresponds to the uppermost surface of the iron strip, while the etched diagram relates to a surface situated at a greater depth.

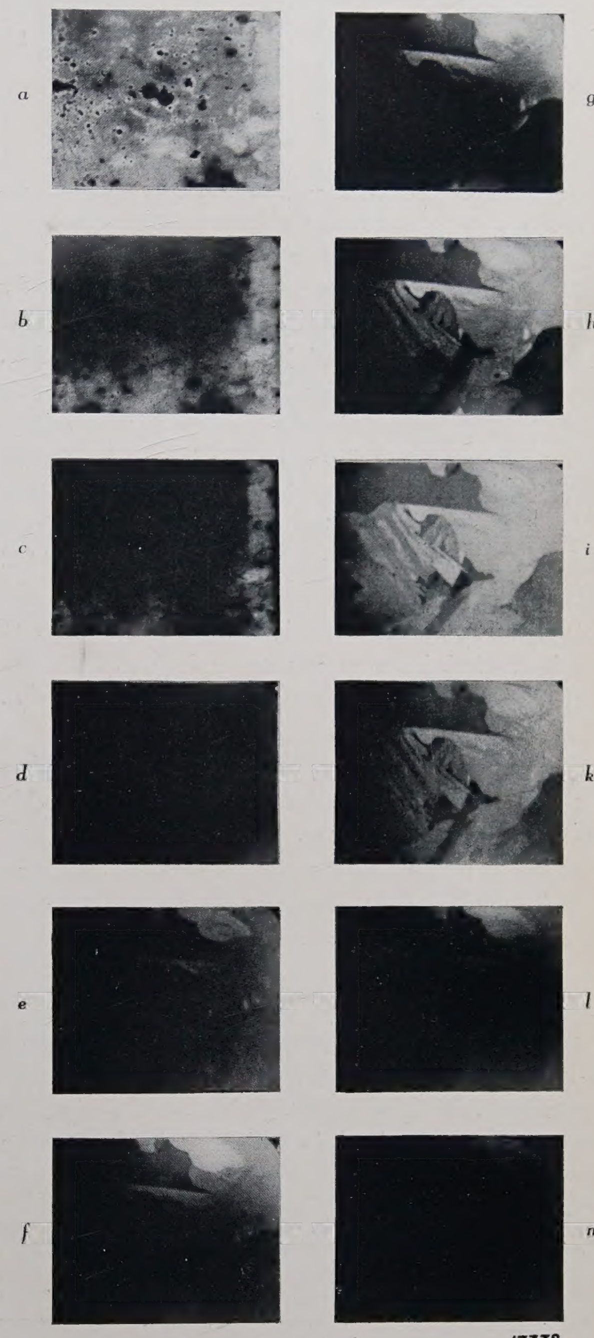


Fig. 5. Appearance and disappearance of the crystal-structure diagram on activating an iron strip with strontium carbonate.

a After depositing the activator on the cathode, in the first instance forming a comparatively thick coating of strontium or strontium carbonate.

b to *d* On heating to a high temperature the activating coating disappears and the emission becomes reduced.

d to *l* The temperature is lowered and an image of the crystalline structure is obtained.

k to *m* On again raising the temperature this image also disappears.

[10]) E. Schenk, Z. Phys., **98**, 753, 1935.

[11]) J. Pohl, Z. techn. Phys., **15**, 579, 1934.
H. Mahl and J. Pohl, ibid, **16**, 219, 1935.

[12]) For this purpose a standard film camera was set up in front of the glass plate *b* with which exposures were made with exposure times of 1 to 2 seconds.

[13]) A temporary increase in emission may occur here. For details of these characteristics in the activation process reference should be made to a paper to be published in Physica.

The process of activation described above may perhaps be explained on the following lines. After depositing the activating coating, the iron strip is in the first place covered with a comparatively thick coating of strontium or strontium oxide, and the emission obtained originates from this coating. As the temperature is subsequently raised, this coating disappears from the surface of the metal, part being removed by volatilisation and part by diffusion inwards. The emission therefore becomes reduced to that of the iron itself, i.e. it disappears almost wholly since the emission of iron at 1100 ° C is very small. If the temperature is now reduced the volatilisation of the strontium from the surface of the iron diminishes to a greater extent than the back-diffusion of the strontium out of the iron. When the temperature has been sufficiently reduced, diffusion will predominate over volatilisation so that the metal coating required for activation is able to form on the surface. On again raising the temperature this coating also volatilises and the emission again falls, as may be seen from the photographs *k-m* in fig. 5 [14]).

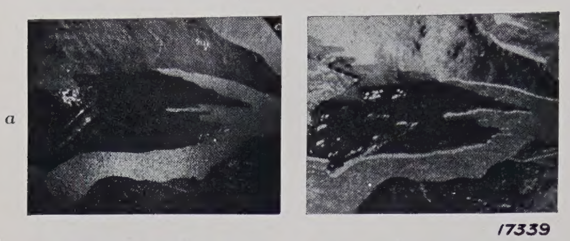


Fig. 6. Crystalline structure diagram of iron on magnification 20 times: Agreement between *a* the emission diagram (at 880 ° C) and *b* the etching diagram (at 20 ° C).

Revealing the Crystalline Boundaries

In the emission diagrams reproduced in figs. 5 and 6 the emission is seen to differ for different crystallites. With different methods of activation diagrams are obtained in which as in *fig. 7a* only the boundaries of the crystallites are well defined. A diagram of this type is obtained particularly on heating cathodes which are still covered with such a thick coating of activating material that the coating itself emits electrons and not the metal beneath it. Since at the boundaries of the crystallites any admixtures in the metal are frequently accumulated, it is possible that the activating coating above these boundaries is present in a different state, i.e. reacts chemically or volatilises more rapidly, than over the crystallites themselves, and that as a result a different emission is obtained [15]). Fig. 7*a* was obtained with nickel iron at a temperature of approx. 700 ° C., and fig. 7*b* with a cathode etched with hydrochloric acid and picric acid. In addition to a number of irregular boundary lines, the etched diagram also includes several which are quite straight (marked with arrows). These are the socalled boundaries, i.e. they separate two crystal lattice areas mutually orientated in twin positions. These boundaries are thus entirely different from ordinary crystal boundaries, where, as already indicated, e.g. admixtures or impurities may be accumulated. It should be noted that the difference in character of these two types of boundary lines is clearly brought out in the electron-optical diagram. While the ordinary crystal boundaries appear very dark, the twinning boundaries can be barely distinguished.

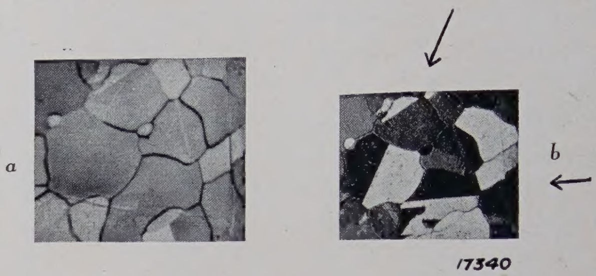


Fig. 7. Emission diagram *a* (at 1100 ° C) and etched diagram *b* at room temperature of nickel iron: In the emission diagram the boundaries of the crystallites can be clearly picked out, while the socalled "twinning boundaries" marked in the etched diagrams by arrows are barely visible.

[14]) According to the above experiment the activation process described here bears a close analogy to observations made in the activation of tungsten containing thorium oxide, cf. E. Brüche and H. Mahl, Z. techn. Phys., **16**, 623, 1935.

[15]) A generally valid explanation of this phenomenon has not yet been advanced as far as we are aware. Cf. e.g. E. Brüche, Z. Phys., **98**, 77, 1935.

Correction. In the article on the „Development of the Coiled-Coil Lamp" Philips techn. Rev. I, 97, 1936 the following corrections to printer's errors should be noted:

1. (Table p. 98): The figures in the last column relate to a wire 0.1 mm in diameter (and not to one of 0.01 mm).
2. (Footnote p. 100) : 1 m³ of air contains approximately 1 cm³ of krypton and 0.1 cm³ of xenon (instead of 10 and 1 cm³ respectively).
3. (Fig. 8, p. 101): In the caption *A* and *B* have been interchanged; the caption should read: *A* for a coiled-coil lamp, *B* for a single-coil lamp. Hence the diminution in efficiency is lower in the case of the coiled-coil lamp.